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16. Abstract

Based on experience gained during the five-year SINSS (Shipboard Ice Navigation Support System) development program, Canarctic has undertaken to specify the functional requirements for a second-generation (G-2) Ice Navigation System.

The procedures and methods used by the navigating personnel for ice navigation are generically described, without reference to existing hardware or data sources. The description includes all three levels of ice navigation activity: strategic, tactical and close-range hazard detection. The data sources used for ice navigation are then discussed at length, outlining their relationship to navigation methods and techniques. Sources now available, under development or proposed are discussed.

The full functional specifications for a second-generation ice navigation system are then given. The specifications cover operational requirements, user interface, navigation techniques and new methods for ice navigation. The specifications also cover hardware and software architecture of the system. Open architecture and real-time system response are heavily emphasized. Memory, data storage and processing speeds are also covered. A review of technology now in use for ice navigation is undertaken to provide the basis for comparison between existing system performance and the G-2 requirements. A brief review of existing technology that may meet the G-2 requirements is presented.

The majority of the G-2 functions and requirements are easily within reach of today's technology. The uniqueness of the G-2 system resides in the way the various techniques and technologies available today will be assembled into a high performance, open architecture and multifunctinal system. The system will provide a platform for the future development of related technologies.

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16. Résumé

En se basant sur l'expérience acquise au cours du programme SINSS de cinq ans, Canarctic a entrepris de définir les exigences d'un système de deuxième génération de navigation dans les glaces (G-2).

Les procédures et méthodes employées par le personnel de navigation pour la navigation dans les glaces sont décrites de façon générique, indépendamment des appareils ou des sources de données disponibles. La description touche les trois niveaux d'activité de la navigation dans les glaces: niveau stratégique, tactique, et de détection à courte portée. Les sources de données utilisées pour la navigation dans les glaces sont discutées en spécifiant leur relation aux différentes méthodes et techniques de navigation. Les sources de données disponibles présentement, en développement ou simplement planifiées sont présentées.

Les spécifications fonctionnelles complètes d'un système de deuxième génération de navigation dans les glaces sont ensuite données. Les spécifications couvrent les exigences opérationnelles, l'interface de commande, les techniques de navigation ainsi que certaines nouvelles méthodes de navigation dans les glaces. Les spécifications concernent l'architecture physique du système ainsi que celle du logiciel. Une architecture décloisonnée ainsi que des performances en temps réel sont fortement préconisés. La capacité mémoire vive, de stockage en masse, ainsi que la vitesse de traitement sont discutés. Une révision des technologies utilisées présentement pour la navigation dans les glaces est faite. Cette révision doit permettre de comparer les performances des systèmes actuels, aux spécifications du système G-2. Une étude brève des technologies pouvant servir à la réalisation du système G-2 est faite.

La technologie d'aujourd'hui est largement suffisante pour la majorité des fonctions et des exigences du système de deuxième génération. Celui-ci sera unique par son agencement des techniques actuelles en un puissant système multifonctionnel à architecture décloisonnée. On pourra y mettre en oeuvre toutes les techniques décrites dans ce document et il nous permettra d'en créer d'autres.

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Navigation dans les glaces, SINSS, traitement d'images, radar nautique, SONAR, satellite, NOAA, dépolarization, rehaussement d'image, positionnement automatique, VME, MULTIBUS II.	Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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We would also like to thank Mr. Ajit Nilakantan and Mr. Fayçal Kahloun for their numerous suggestions on radar signal processing and their review of Appendix C of this report.

Executive Summary

Canarctic has recently completed the five-year Shipboard Ice Navigation Support System (SINSS) development program, whose purpose was to develop an ice intelligence system on board the M.V. Arctic which would enable the vessel to safely and efficiently navigate through heavy sea ice conditions. The SINSS program resulted in the specification of a first generation ice navigation system comprising strategic satellite information (VIEWFAX), a strategic and tactical airborne radar imagery display system (STAR-VUE), and a tactical and close range hazard detection marine radar system (MARINE-VUE). The existing hardware base of SINSS has evolved slowly based on numerous field trials on board the M.V. Arctic. What resulted was a first-generation system operating to the limits of the hardware capabilities. In this project, the functional requirements of an ice navigation system were identified, and the sources and throughput of data were described to serve as a design specification for an advanced and integrated second-generation ice navigation system.

The procedures followed by the navigators in executing the strategic, tactical and close range elements of an ice navigation strategy are described. This description is not based on the hardware used in ice navigation, nor does it specify the precise information sources used during navigation. Rather, the analysis provides a generic description of the procedures followed, not influenced by hardware bases or data sources now available. The information sources used to satisfy the needs of an ice navigation system are specified. This analysis includes sources now available as well as an investigation of future products that are either under development or proposed.

At the strategic planning level, a review of the data sources currently in use is provided, including the following:

- A description of the NOAA and METEOR APT products received on board the M.V. Arctic.

- A description of the A.E.S. ice charts and historical data sets.

- Future products that are either planned or proposed from such sources as RADARSAT and ERS-1, which could provide input to the strategic planning level of SINSS, are investigated.

At the tactical level, the following are given:

- A description (i.e., data rate, format) of the SAR provided by the Comprehensive Ice Reconnaissance Service as well as other downlinked microwave data.

- A description of the marine radar system used in the tactical stage of SINSS (Arctic Marine Radar).

- An investigation of current and future tactical uses of data gathering systems such as helicopters and passive microwave radiometer platforms.

At the close range ice hazard detection level, the following are presented:

- A description of how the marine radar data is used in the close range detection of ice hazards.

- An investigation of future sources potentially available for ice harzard detection, such as SONAR.

The various formats of data available to the system were used to develop the functional specification of a data reception and storage facility for the second generation system. The functional specification is presented in such a way that the design of the new system will consider the handling of both existing and future sources of data. The speed, volume of data reception, and storage which the new system must be capable of handling, is specified. The user interface component of the system is defined. The functional specification for the user interface relies heavily on the definition of the operators requirements. The user interface includes a description of the display most appropriate for each source of data (speed, data pan, zoom function, hard copy requirements, etc.).

A review of technology now in use for ice navigation (i.e., first generation ice navigation system) is presented so that a comparison of the second generation ice navigation system requirements may be made to existing system performance. A brief review of existing technology that may meet the requirements of the second generation system was made. The results of the review are presented in the form of a collection of hardware that can be used to implement most of the functions specified in the report.

The majority of the G-2 functions and requirements are easily within reach of today's technology. The uniqueness of the G-2 system resides in the way the various techniques and technologies available today will be assembled into a high performance, open architecture and multifunctional system. The G-2 system will allow the implementation of all the techniques described in this document, and will provide a platform for the future development of related technologies.

Sommaire

Canarctic a récemment mené à bien le programme sur cinq ans de création d'un système de bord d'aide à la navigation dans les glaces (Shipboard Ice Navigation Support System ou SINSS). Ce programme visait à mettre au point à bord du N.M. Arctic un système d'information sur les glaces qui permette à ce navire de naviguer en toute sécurité et efficacité dans des conditions glacielles difficiles. On a ainsi pu concevoir un système de navigation glacielle de première génération comprenant une source d'information stratégique par satellite (VIEWFAX), un système stratégique et tactique d'affichage d'images de radar aéroporté (STAR-VUE) et un système de radar marin de détection tactique et à courte portée de conditions dangereuses (MARINE-VUE). Le matériel en place SINSS a lentement évolué grâce à de nombreux essais réalisés à bord du navire et ce système de première génération est maintenant exploité à la limite de ses capacités matérielles. L'établissement des exigences fonctionnelles d'un système de navigation dans les glaces et la description des sources et des taux de transmission de données ont été à la base de la conception d'un système avancé et intégré de deuxième génération.

On décrit les procédures suivies par les navigateurs dans l'exécution des éléments stratégiques, tactiques et <<courte portée>> d'un programme de navigation glacielle. Cette description n'est pas fondée sur le matériel utilisé en navigation et n'implique pas non plus les sources d'information précises servant durant la navigation. Il s'agit plutôt d'une description générale indépendante du matériel et des sources de données actuellement disponibles. On précise les sources d'information employées pour les besoins d'un système de navigation. Le cadre d'analyse comprend les sources aujourd'hui disponibles ainsi que les produits en cours d'élaboration ou proposés.

Au niveau de la planification stratégique, on passe en revue les sources actuelles. Il y a notamment :

- une description des images APT des satellites NOAA et METEOR reçues à bord du N.M. Arctic;
- une description des cartes des glaces et des ensembles de données chronologiques du Service de l'environnement atmosphérique;
- un examen de produits prévus ou proposés de sources comme RADARSAT ou ERS-1, qui pourraient alimenter le niveau de la planification stratégique du SINSS.

Au niveau tactique, on présente les éléments suivants :

- une description (taux de transmission et structure) des images ROS fournies par le <<Comprehensive Ice Reconnaissance Service>> et d'autres données télémétriques;

- une description du système de radar marin (Arctic Marine Radar) utilisé au niveau tactique du SINSS;

- un examen de l'emploi tactique actuel et futur de moyens de collecte de données comme les détecteurs héliportés et les plates-formes radiométriques à hyperfréquences passives.

Au niveau de la détection à courte portée, on offre les éléments suivants :

- une description de l'utilisation du radar marin pour la détection de conditions glacielles dangereuses;

- un examen de futures sources possibles de données de détection comme le SONAR.

La structure des diverses sources de données disponibles a servi à établir les caractéristiques fonctionnelles d'un dispositif de réception et de stockage de données pour le système de deuxième génération. On présente ces caractéristiques de manière que la conception du nouveau système tienne compte des sources actuelles et futures. On précise la vitesse et le volume de réception et la capacité de stockage. On définit aussi l'interface utilisateur, dont la carctérisation fonctionelle se fonde largement sur la définition des besoins des opérateurs. On décrit à cet égard l'affichage qui convient le mieux à chaque source de données (vitesse, survol, grossissement, impression d'images, etc.).

On examine la technologie maintenant employée (système de première génération) pour la navigation dans les glaces et on peut ainsi comparer les exigences du système de deuxième générations au rendement du système en place. On voit brièvement quelle technologies existante pourrait répondre aux besoins du système de deuxième génération. On présente dans cette optique une série de composantes (matériel) permettant de réaliser la plupart des fonctions qu'indique le rapport.

La technologie d'aujourd'hui est largement suffisante pour la majorité des fonctions et des exigences du système de deuxième génération. Celui-ci sera unique par son agencement des techniques actuelles en un puissant système multifonctionnel à architecture décloisonnée. On pourra y mettre en oeuvre toutes les techniques décrites dans ce document et il nous permettra d'en créer d'autres.

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1. Introduction

Canarctic has recently completed the five-year Shipboard Ice Navigation Support System (SINSS) development program. The purpose of the five-year SINSS program was to develop an ice intelligence system on board the M.V. Arctic which would enable the vessel to safely and efficiently navigate through heavy sea ice conditions. The SINSS program resulted in the specification of a first generation ice navigation system comprising strategic satellite information (VIEWFAX), a strategic and tactical airborne radar imagery display system (STAR-VUE), and a tactical and close range hazard detection marine radar system (MARINE-VUE).

The existing hardware base of SINSS has evolved slowly based on numerous field trials on board the M.V. Arctic. Multi-season experience using an ice navigation system is required to ensure that all functional aspects of the system are specified. As a need was identified, during the development program, functions were added or modified to the existing hardware base to attempt to meet the needs. What has developed is a first generation system comprising three independent systems (VIEWFAX, MARINE-VUE, and STAR-VUE) which are operating at the limits of the equipment capability. Consequently, future upgrades identified at the completion of the SINSS program cannot be implemented on the existing hardware base. In this project, the functional requirements of an ice navigation system were identified, and the sources and throughput of data were described, to serve as a design specification for an advanced and integrated second generation ice navigation system.

This report summarises five years of research in ice navigation, extracting from this experience those elements that have been proven functional and can be used in the implementation of a second generation Ice Navigation System. Section 2 outlines the user requirements for ice navigation. Section 3 gives a description of the information sources that can be used to meet the user requirements. Section 4 describes the techniques and methods to use in order to meet the operator requirements defined in

Section 2. In Section 5, the system hardware specifications are outlined in terms of processing speed, data storage capacity and general architecture. Section 6 deals with data quantity and processing speed calculations. Section 7 sets a comparison basis by outlining the status of present SINSS technology. Section 8 evaluates the overall feasibility of the G-2 system as described in this document.

1.1 Project Objective

The objective of this project was to define the functional specification of a second generation ice navigation system. The purpose of this functional specification is to act as the design framework from which a second generation ice navigation system may be constructed.

1.2 Specific Objectives

Canarctic called upon the expertise gained from both operational and technical experience acquired during the SINSS program to produce a functional specification of a second generation ice navigation system. The following analyses were undertaken:

1) Define user requirements for an ice navigation system.
2) Define and describe the sources of information used in an ice navigation system.
3) Define the data format and throughput requirements for each source (i.e., data speed, storage requirements etc.)
4) Describe the use of each data source and define the user interface and system performance required for a second generation ice navigation system (i.e., speed of data display, data pan and zoom requirements, etc.)
5) Review technology in use for ice navigation and conduct a brief survey of existing technology that can be used for the implementation of the Second Generation Ice Navigation System

2. Operator Requirements

The experiences gained by Canarctic in executing the Shipboard Ice Navigation Support System have resulted in the specification of three levels in the process of ice navigation: strategic planning, tactical navigation and close range hazard detection. The strategic planning level involves vessel routing decision days, weeks or months in advanced of the actual voyage. The tactical navigation level involves vessel routing decisions within hours ahead of the vessel while close range ice hazard detection involves decisions affecting immediate helm orders to avoid ice conditions minutes ahead of the vessel. Figure 2.1 presents a conceptual representation of SINSS. In this report, a generic description of the needs of the navigator at each of the three levels within SINSS is provided.

2.1 Strategic Planning

The experiences of Canarctic in operating the M.V. Arctic in the eastern Canadian Arctic has demonstrated that the strategic planning level of SINSS is a long term process spanning many months prior to the voyage. Three stages have been identified in the strategic planning level of SINSS; long term planning, medium term planning, and ship based strategic planning. The data needs of each level are summarized in Table 2.1 and described in detail below.

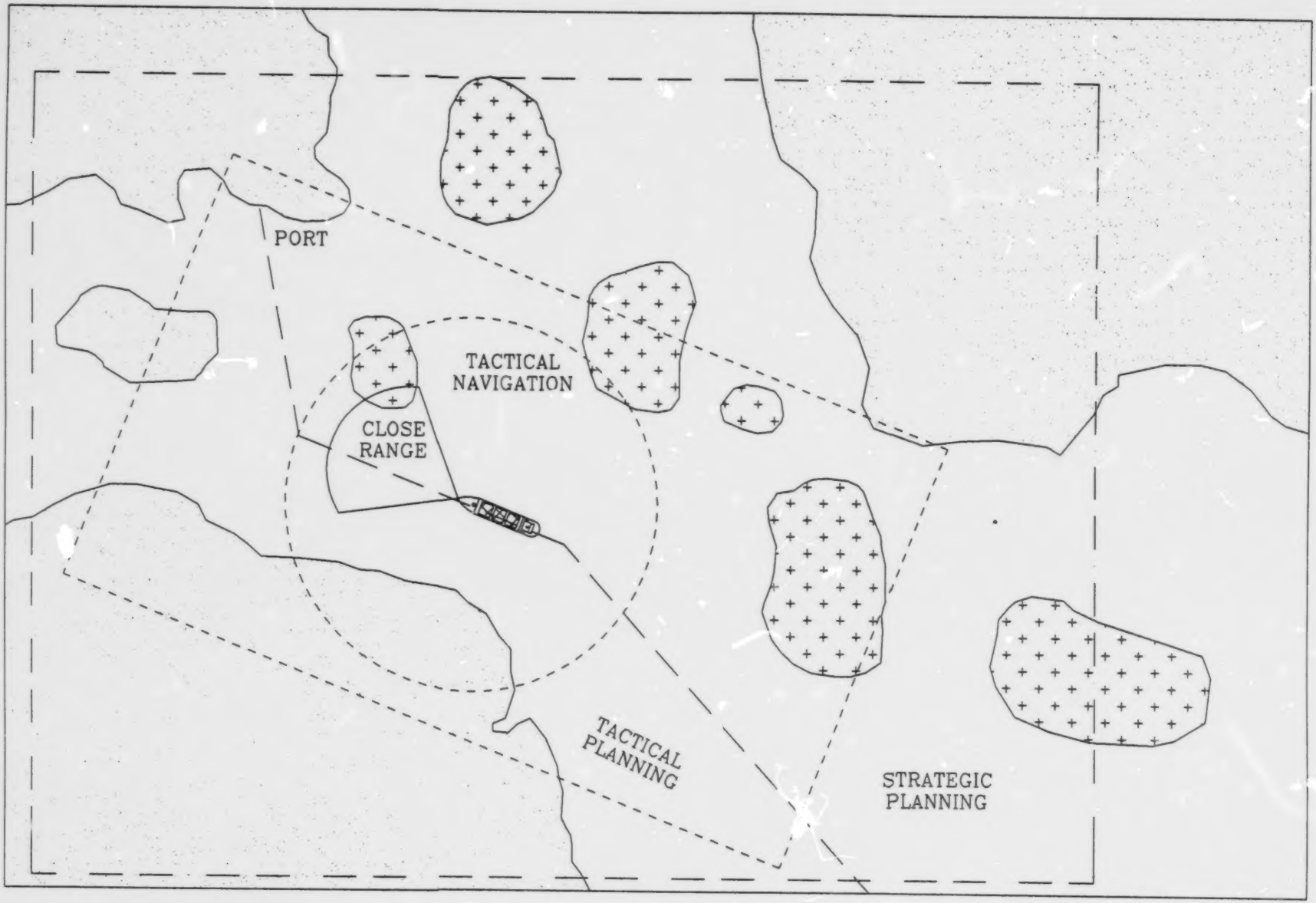


FIGURE 2.1: Conceptual Chart of SINSS

Table 2.1
Information Requirements
Strategic Planning

Long Term

Shore-based analysis 6 months or more before voyage

- to gain a good understanding of ice conditions based on the study and analysis of historical trends
- need to know what range of ice conditions may be expected so that the vessel schedule may be properly developed
- Analysis of how vessel performed during previous voyages through similar conditions
- based on historical information only. Could be formally presented in a passage planning manual

Medium Term

Shore-based analysis two weeks to three months before voyage

- information is gathered on the existing ice conditions present in the shipping channels as well as all channels known to feed ice (from long range analysis) into the shipping channels
- information should be of sufficient resolution (i.e., nominal 100m) that will show ice type, concentration and ridging using a proven objective method
- nowcast, hindcast and forecast meteorological data are gathered including:

    1) Temperature (mean daily as well as M and FDD)
    2) Winds (surface pressure charts)
    3) Snow cover and snow fall

- based on the existing ice and meteorological conditions, forecasts are made as to the likely conditions that will be present at the time of the voyage based on past experience gained from the long range analysis

Short Term

Ship-based analysis two days to two weeks prior to the voyage and ongoing during the voyage

- information gathered on board vessel of ice conditions along the entire route prior to departure from port
- the analysis and forecast of ice conditions produced in the medium range is compared to actual developing conditions. Updates to the forecasts are made
- since detailed information collected in medium range less detail required in short term. Resolution in the 1-4 km range required but should be from proven and objective source
- synoptic weather information collected including:

    1) Wind
    2) Temperature
    3) Snow Fall

2.1.1 Long Range Strategic Planning

Strategic planning begins at the time of vessel schedule development which may occur from several months to a year ahead of an actual voyage. Clearly, one cannot predict with any accuracy the precise ice conditions to be encountered by a ship six or more months in advance. However, based on historical information on ice conditions and the known performance of a vessel in ice, a marine manager will be able to determine the range of ice conditions likely to be encountered at a given location at a given time of year. Therefore, the expected date a vessel will be able to access a port as well as the length of time the voyage will take are determined from the historical data analysis. At Canarctic, this level is accomplished through the numerous ice regime studies undertaken by Canarctic (examples include Gorman 1990, Gorman and Sneyd 1986, Canarctic and Norland 1985) as well as the analysis of data from the five year M.V. Arctic vessel performance and monitoring program (Norland 1988). An example of a summarized historical analysis is included in Appendix A.

The data used in the historical analysis range in scale and resolution from as low as one or two kilometres resolution over several thousand square kilometres to twelve metres over several hundred square kilometres. Ice detail discernable includes ice type and concentration to the level of detail provided by the data as well as the identification of areas of significant ridging to the vessel. Regional temperature and wind data corresponding to the ice information is also, on occasion, used. Vessel performance data includes average speed made good and fuel consumption through various ice conditions along historical tracks at hourly intervals.

2.1.2 Medium Range Strategic Planning

Whereas long range strategic planning relies on historical data sets, medium range strategic planning addresses actual ice conditions developing along the navigable waterways to the intended port. Included in the analysis are adjoining waterways that are

known (from the long range analysis) to feed ice into the shipping channels. Information should be of sufficient resolution (i.e., nominal 100m) to show ice type and concentration over the shipping channels using a proven and objective method. Nowcast, hindcast and forecast meteorological data are collected including, in order of importance:

1) Temperature - mean daily trend and deviation
- freezing and melting degree day accumulations (FDD and MDD)

2) Winds - mean daily
- direction and force (from pressure chart)

3) Snow Fall

Based on the existing ice and meteorological conditions, forecasts are made as to the likely conditions that will be present in the shipping channels, based on the knowledge of how the ice behaved in the past (from the long term analysis). Such a forecast may include the expected timing of consolidation or fracture of an ice cover or the expected movement of old ice into the shipping channel. At Canarctic, this level of strategic planning is accomplished thought the issuing of status reports on a bi-weekly basis throughout the shipping season. Data are collected from the Government of Canada's Ice Centre and correlated to Canarctic's long term ice studies to produce an analysis and forecast of ice conditions that are significant to voyage planning for the M.V. Arctic. In Appendix B can be found an example of such a status report. These reports are produced in the Canarctic office and are used by the Operations Division for schedule development and bunker plans. They are also sent to the vessel to aid in the short range strategic plan.

2.1.3 Short Range Strategic Planning

Information is gathered on board the ship on ice conditions along the entire route of the vessel prior to the ship departing port and on a continuous basis during the voyage. The analysis and forecast of ice conditions produced in the medium range are compared to overall conditions developing along the route. Updates are made to the medium range forecast. Since relatively detailed information was gathered in the medium range, the ship based information need only be of a regional nature to follow gross ice features such as consolidated ice edges and significant concentrations of ice. For example, if an area of five tenths old ice in medium floe sizes was identified east of Philpots Island in northern Baffin Bay in the medium range planning, then the movement of this ice over the period before the ship arrives in the area needs to be followed on board the vessel. The vessel does not need strategic information that will allow each ice floe to the identified (medium floes are 100-500m across) but rather would allow the ice field to be monitored. Information in the 1-4 km resolution range would be sufficient but should be objective and proven accurate for ice type, concentration and ridging determination.

Synoptic weather conditions are monitored in the following order of importance:

1) Regional wind - determined from pressure patterns
2) Temperature

Wind data is more important than temperature as the pressure fields developed by regional winds during the voyage are now more critical than any thickening or weakening of the ice cover which may occur over the ensuing days due to temperature variations.

The end result of the strategic planning analysis is the identification of when and where ice that may prove difficult for the ship will be encountered. The area identified will form the focus for the tactical navigation stage of SINSS.

2.2 Tactical Navigation

The tactical navigation component of SINSS is executed over the portion of the route where difficult ice will be encountered by the vessel. Ice information collected at this level should be of sufficient resolution to identify small ice floes or ice cakes in the range of 15-25 metre resolution. Ice detail of type, concentration and ridging must be discernable to this resolution. Canarctic has found that the tactical navigation level of SINSS has two stages; tactical planning and tactical navigation. A schematic representation of the tactical navigation stage of SINSS is presented as part of Figure 2.1 and the information needs are summarized in Table 2.2.

2.2.1 Tactical Planning

Tactical Planning involves the receipt and analysis of ice information over one or two days sailing time in front of the vessel. Typically, tactical planning covers the portion of the total route which contains the most difficult ice of the transit. The data is received on board the vessel at the ice cake/small floe level of detail over the transit corridor selected in the strategic planning stage. The position of the vessel within the ice information is identified. The tactical route of the vessel around the difficult ice is selected and the waypoints of the intended course are identified. The selected waypoints are transferred from the ice information to the navigation chart.

Table 2.2
Information Requirements
Tactical Navigation

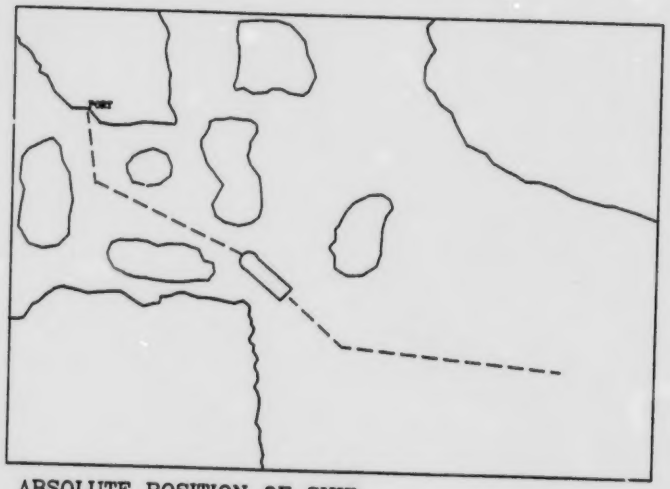
Tactical Planning	
Review of entire tactical section of route over one or two days sailing time	- information collected over area where difficult ice to be encountered at a resolution of 15-25 metres. Need information on ice type, concentration and ridging - complete tactical route selected from acquired information - entire area should be viewable at full resolution at one time
Tactical Navigation	
Floe by floe navigation along the route	- need to determine relative position of vessel within tactical ice information - need continuous updated ice information on board ship to correlate to tactical planning information - ice information needs to be of the same resolution as tactical planning data at a range of at least 6 n. miles in front of the vessel - tactical planning information displayed at least 18 n. miles in front of the vessel for correlation to continuously collected data - need to easily correlate the two tactical information sources together to follow the vessel's progress along the tactical navigation course

2.2.2 Tactical Navigation

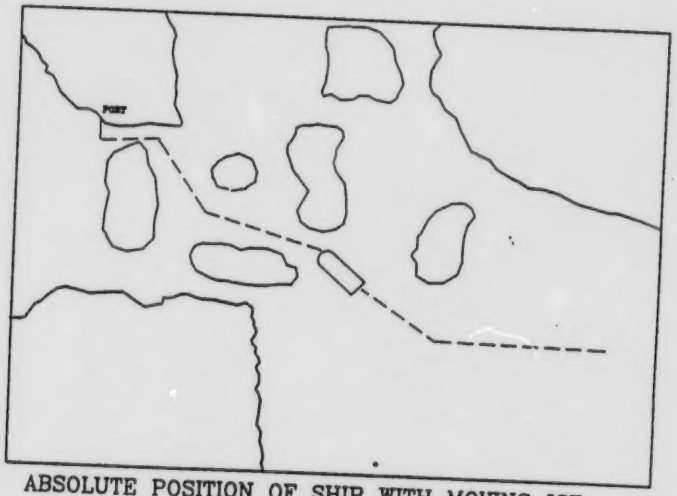
Once the tactical route and waypoints have been selected, the position of the vessel relative to the ice information is determined. The progress of the vessel along the intended tactical course is monitored by identifying the location of the ship's position relative to the ice features present on the tactical ice information, not the absolute geographic position relative to the waypoints selected in the tactical planning stage. There is an important distinction to be made between the absolute position of the vessel (i.e., latitude/ longitude) and the relative position of the vessel compared to the ice. Since ice continually moves through a channel, the geographic position of each ice floe is only accurate at the time the ice information is collected. However, Canarctic has noted that the relative position of each ice floe or feature often remains intact as the ice continues to move for one or more days after the data was collected. Consequently, the route selected around the ice feature remains accurate despite the movement of the ice cover although the geographic position of the waypoints no longer remains accurate. Figure 2.2 is a representation of the difference between relative and absolute ship positioning as it pertains to ice navigation.

The floe by floe monitoring of the vessel's course along the imagery requires that the ship be able to collect, on a continuous base, updated information on the location of the vessel within the ice field. Such information should have the same characteristics and resolution as the original tactical ice information and at a range of at least 6 nautical miles ahead of the vessel.

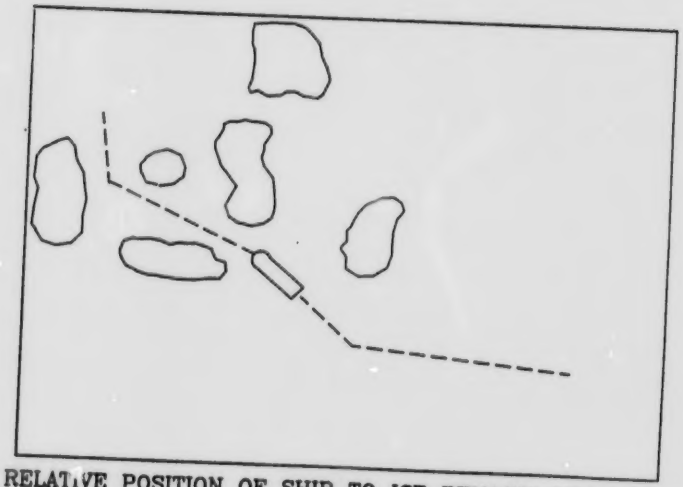
By comparing the continuously collected information to the previously collected tactical ice data, the vessel is maintained on the selected tactical course. This procedure involves correlating features on the continuously collected ship-based information, such as ice floes or leads, to the same features on the regional tactical coverage. In this way, the precise position of the vessel can be identified so that helm orders to maintain the vessel on the tactical course may be given. This procedure of correlation between the two data sets should be as automated as possible using simple to use and operate equipment to minimize errors and time demands.



ABSOLUTE POSITION OF SHIP



ABSOLUTE POSITION OF SHIP WITH MOVING ICE



RELATIVE POSITION OF SHIP TO ICE REMAINS UNCHANGED

FIGURE 2.2

COMPARISON BETWEEN ABSOLUTE AND RELATIVE POSITION OF VESSEL TO ICE AND LAND

2.3 Close Range Ice Hazard Detection

A critical component of an ice navigation strategy is the ability to avoid an impact with small but dangerous ice hazards directly in front of the vessel. These features often are point targets on ice information and can be difficult to detect. Such ice features include small multi-year floes and icebergs, often in sizes as small as five metres or less across. What is needed is the ability to detect 100% of the small ice fragments such as bergy bits and old ice floes as small as five metres across at a range of one nautical mile infront of the vessel in all ice and sea states as well as weather conditions. This is the most difficult aspect of SINSS. Should such information not be available, then the forward progress of the vessel is slowed or stopped. By slowing the vessel, there may be sufficient time to avoid any ice detected within one nautical mile or the ice may be impacted, based on the structural strength of the vessel, without damage. This is termed "safe speed" given the prevailing ice conditions. The information needs for close range ice hazard detection on board the vessel are summarized in Table 2.3.

Table 2.3
Information Requirements
Close-Range Hazard Detection

Close Range	
Within 1 nautical mile of vessel - continuous	- all weather, all ice and sea state capability
	- need to detect old and glacial ice down to 5 metres in diameter

3. Information Sources

The sources of information available to an ice navigation system are wide and varied ranging from satellite and airborne systems to ship-based and shore-based methods. A review of the existing or planned information systems that may be of use to the second generation ice navigation system was undertaken by Canarctic. A summary of the systems identified and the data characteristics of each is provided in Table 3.1. In this section, a brief description of each system is provided.

3.1 NOAA Satellites

The National Earth Satellite Service (NESS) of the American National Oceanic and Atmospheric Administration (NOAA) operates a network of geostationary and polar orbiting environmental satellites. The satellite series of most interest to ice information users are the TIROS (Television Infra-Red Observations Satellite) and GOES (Geostationary Operational Environmental Satellite).

3.1.1 TIROS

The TIROS series began operation with the launch of the TIROS-1 in 1960. The primary sensor package on the early TIROS was a television type camera called the Return Beam Vidicon (RBV) with data being transmitted to earth via a VHF (very high frequency) APT (Automatic Picture Transmission) service.

A major change in the design and operation of the TIROS satellites, and the one of most importance to ice reconnaissance, came with the ITOS (Improved TIROS Operational Satellite) in 1970. The RBV sensor was replaced by a two channel electronically scanning radiometer, the Very High Resolution Radiometer (VHRR). Concurrent with the VHRR was the addition of the High Resolution Picture Transmission (HRPT) service. Due to the high volume generated by the VHRR sensor,

a wide band width gigahertz frequency data bus was required from the satellite to ground stations and this was met with the HRPT. With the launch of ITOS-2 in 1972, the operational name of the satellite series was changed from TIROS to NOAA. The ITOS series of satellites were launched as NOAA-2 to NOAA-5 between 1972 and 1976. The VHRR sensor used on NOAA-2 to NOAA-5 was a two channel multi-spectral scanner (MSS) sensing in the visual and thermal infra-red regions with a swath width of 2580 km and a spatial resolution of 0.87 km (RESORS, 1986).

The next generation of NOAA satellites, TIROS-N, was launched into service with NOAA-6 in 1979 and represents the present day NOAA series. The VHRR of the ITOS series was replaced by the Advanced Very High Resolution Radiometer (AVHRR) on the TIROS-N series. The AVHRR is a five channel MSS sensing in the visible, reflected infra-red and thermal regions of the spectrum with a swath width of 2700 km. In Table 3.2 can be found a summary of the AVHHR sensor characteristics. The AVHRR sensor has two series, the AVHRR-1, used on board NOAA-6 and the AVHRR-2 used on subsequent NOAA satellites. The AVHRR-1 was an experimental version and lacked the fifth (11.5 - 12.5 μm) thermal infra-red channel of the AVHRR (Barns and Smallwood, 1982).

Table 3.1
SINSS G-2
Data Source Specifications

Sensor/Instrument	Type	Availability of Data	Swath Width/Range	Resolution	Transmission/Data Rate
AVHRR-MSS (NOAA)	Visual Thermal IR .5A-12.5μm	Real time downlink	2700 km	1-4 km	APT 137.5 MHZ 8 kbps 137.62 MHZ HRPT 1698.0 MHZ 665 kbps 1707.0 MHZ POMS 1707.0 MHZ 3.5 mbps
VISSR-MSS (GOES)	Visual Thermal IR .54-11.0μm	30 minutes delay from NESS broadcast	Full disk view	4-7 km	N/A 1.8 mbps
DMSP-OLS	Visible Thermal IR .4-12.80μm	Real time encoded	2900 km	.6 km	HRPT 2252.5 MHz 1.024 mbps
DMSP-SSM/I	Passive Microwave 22.5-88.5 GHz	Data relay via CMC Toronto	1400 km	35 km	Telephone modem connection
METEOR	Visible Thermal IR .5-12.0μm	Real time downlink	2700 km	1-3 km	APT 137.3 MHz 8 kbps 137.4 MHz 137.85 MHz
COSMOS	SLAR 9.8 GHz	Real time downlink	450 km	2-4 km	APT 137.4 N/A
ERS-1	SAR 5.3 GHZ	Ground processing required	100 km	530 m	8215 MHz 105 mbps Communication Sat. Re-broadcast
RADARSAT	SAR 9.8 GHz	Ground processing required	100 km selectable to 500km	30 m - 100 m	8215 MHz 105 mbps 8400 MHz Communication Sat. Re-broadcast

Sensor/Instrument	Type	Availability of Data	Swath Width/Range	Resolution	Transmission/Data Rate
CAL SLAR-100	SLAR 9.8 GHZ	Real time downlink	50 or 100 km (dual sided)	20-780 m	"S" Band 2300 GHz 1.4 mbps
CIRS-SAR	SAR 9.8 GHz	Real time downlink	50 or 100 km (dual sided)	15-25 m	"S" Band 2300 GHz 1.4 mbps
STAR-1	SAR 9.8 GHz	Real time downlink	23 or 46 km (single sided)	12-16 m	219 MHz 280 kbps
AIMR	Passive Microwave	Ground processing required	Altitude dependent (3.2A)	Altitude dependent 2.4 (A/57)	None available
Arctic Marine Radar	Marine Radar 9.8 GHz	Real time ship-based display	3-12 nautical mile range	Varies with range	Ship-based 20 MHz Bandwidth 1.4 KHz PRF
SBR	Passive Microwave	Ship-based processing 5 minute display time	100 m	Variable width range	N/A
SONAR	SONAR 36 KHz Pulse (will vary)	Real time ship-based display	.5-1.0 nautical mile	N/A	N/A

Table 3.2
AVHRR Sensor Characteristics

Channel	Resolution	Wavelength	Swath Width
1 *	1.1 km	.58-.68 μm	2700km
2	1.1 km	.725-1.10 μm	2700 km
3	1.1 km	3.55-3.93 μm	2700 km
4	1.1 km	10.5-11.56 μm	2700 km
5 **	1.1 km	11.5-12.5 μm	2700 km

* AVHRR/1 .58-.90 μm
** AVHRR/1 Lacked channel 5
(Adapted from RESORS 1986, Barns and Smallwood 1982)

The output from the AVHRR of the existing NOAA satellites is broadcast via two methods; the APT format using a VHF downlink and the HRPT format using an S band frequency.

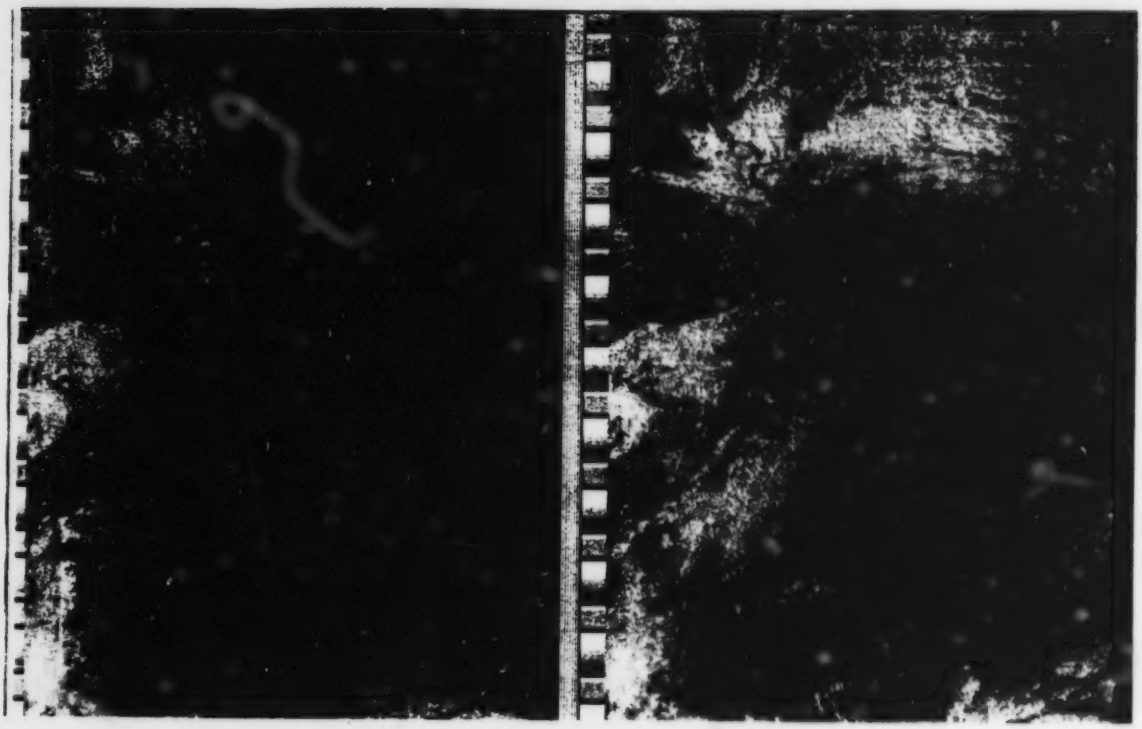
The APT transmission from the NOAA satellite consists of two bands transmitted simultaneously. The choice of which of the five channels of the AVHRR that is to be transmitted at any one time is made at the NOAA satellite command centre in the United States. Every third line of the two selected channels is averaged by an on board digital processor. The averaging creates a nominal along scan resolution of 4 km and is undertaken in such a way as to reduce the distortion introduced by the curvature of the earth's surface. The two averaged channels are converted to an analogue signal, time multiplexed along with calibration data and are amplitude modulated on a 2.4 KHz carrier which is in turn frequency modulated on to the 137 MHz transmission of the APT (Wannamaker, 1984). The APT frequencies transmitted from the NOAA satellite are 137.50 and 137.62 MHz and can be received by using a simple omni-directional antenna.

The two channel APT transmission includes calibration and channel identification information. Figure 3.1 presents an example of an APT image and the meaning of each data bar in the transmission.

The HRPT transmits all 5 channels simultaneously at full resolution over an S band downlink. Unlike the APT, these channels are transmitted in real-time with no on board pre-processing at the full 1.1 km resolution of the sensor (at nadir). Data is transmitted in digital format at 665 kbps at one of two frequencies (1698.0 MHz or 1707.0 MHz). Much more complicated reception equipment is required to receive HRPT data than APT data. A parabolic tracking antenna (gyro stabilized for shipboard use) and image display equipment is required for the ground station. An example of an image from one channel of the HRPT transmission along with a description of the frame format is presented in Figure 3.2. A comparison between an HRPT received image and an APT image is presented as Figure 3.3.

The NOAA/AVHRR sensor is likely the most used sensor for ice reconnaissance. The data is used as the corner stone of the historical analysis of ice conditions spanning 15 years or more of a continuous record. In addition, the direct reception of the data on board ship, (either via APT or HRPT) is useful for all stages of strategic planning.

The NOAA satellite program is well supported within the U.S. as well as through several international agreements such that the long-term continuation of data is assured. A number of upgrades are planned with the NOAA satellites which include the new series named the Polar Orbiting Meteorological Satellite (POMS) which is expected to replace the current series of satellites later this decade. The data transmission rate of the HRPT broadcast service from the POMS is expected to increase from the current rate of 665 kbps (kilo bits per second) to approximately 3.5 mbps. The planned change in data rates will be undertaken in such a way that minimizes the impact on current users, by the use of data encoding and modulation techniques (Fischer 1989).



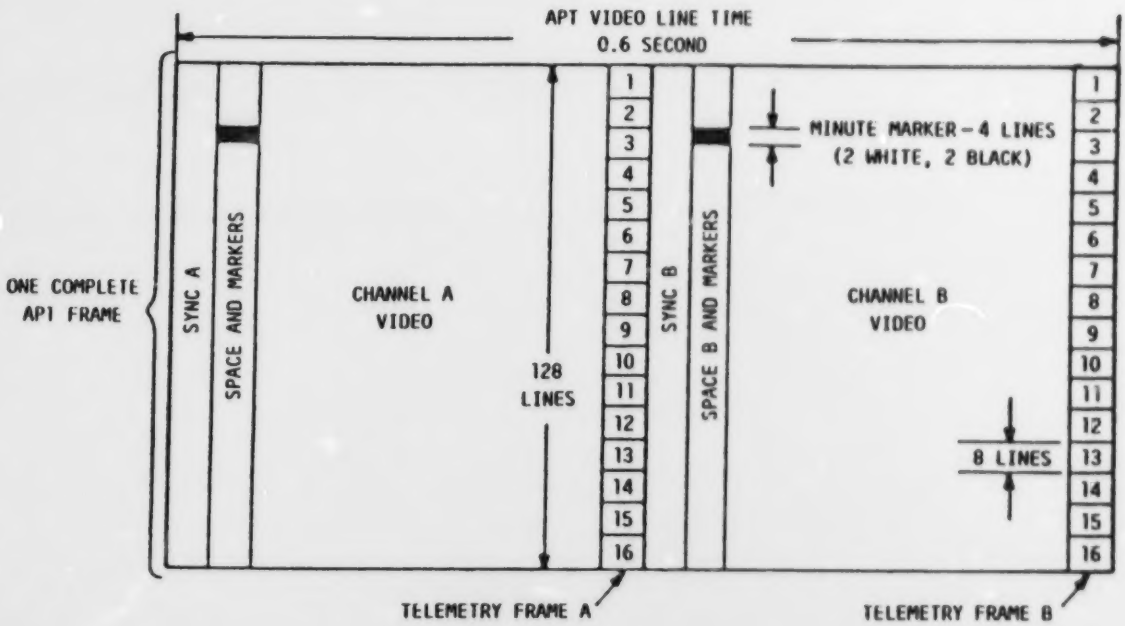
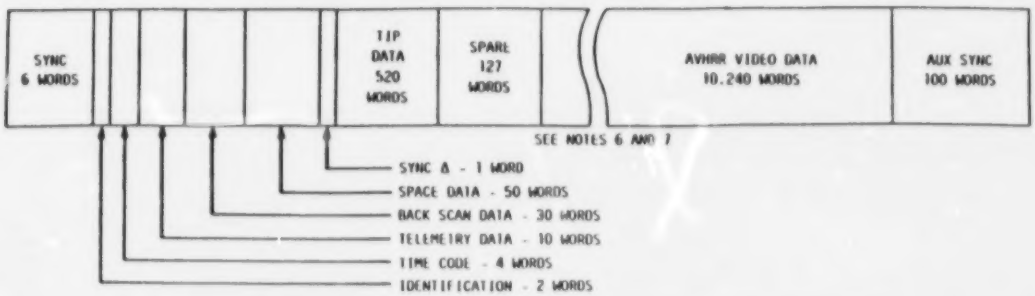


Figure 3.1 APT image and frame Format



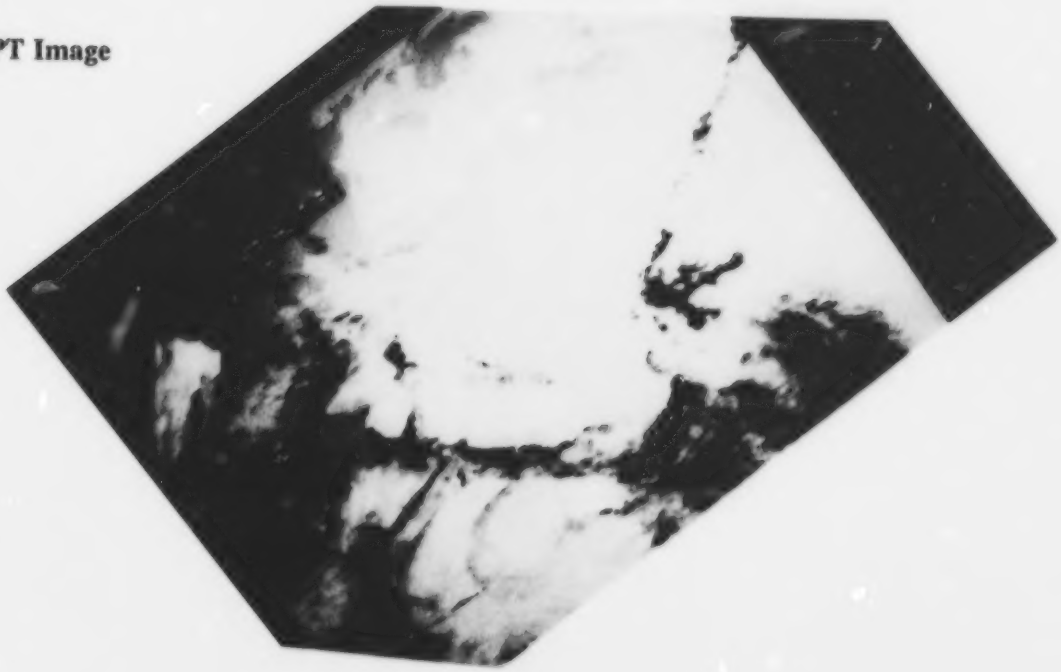
TELEMETRY WORD ALLOCATIONS	ID WORD BIT ALLOCATIONS	
	1ST ID WORD	2ND ID WORD
1-5 RAMP CALIBRATION 6 CHANNEL 3 TARGET TEMP (5 POINT SUBCOM) 7 CHANNEL 4 TARGET TEMP (5 POINT SUBCOM) 8 CHANNEL 5 TARGET TEMP (5 POINT SUBCOM) 9 CHANNEL 3 PATCH TEMP 10 SPARE	1 SYNC ID 2-3 FRAME ID 4-7 SATELLITE ADDRESS 8 RESYNC MARKER 9 INPUT FROM AVHRR/PH CODE 10 DATA 1	(SPARE) CONTENTS UNDEFINED

NOTES:
(1) MINOR FRAME LENGTH - 11,090 WORDS
(2) THREE MINOR FRAMES PER MAJOR FRAME
(3) MINOR FRAME RATE - 6 FRAMES/SECOND
(4) WORD LENGTH - 10 BITS/WORD
(5) WHERE BIT CONTENTS OF LAC WORDS ARE SPECIFIED (AS IN NOTE 7), THE SPECIFICATION APPLIES PRIOR TO DATA RANDOMIZING
(6) HRPT OUTPUT - ALL SPARES ARE 10TH DEGREE P-N CODE (BAR)
(7) LAC OUTPUT - ALL SPARES ARE DATA "0"

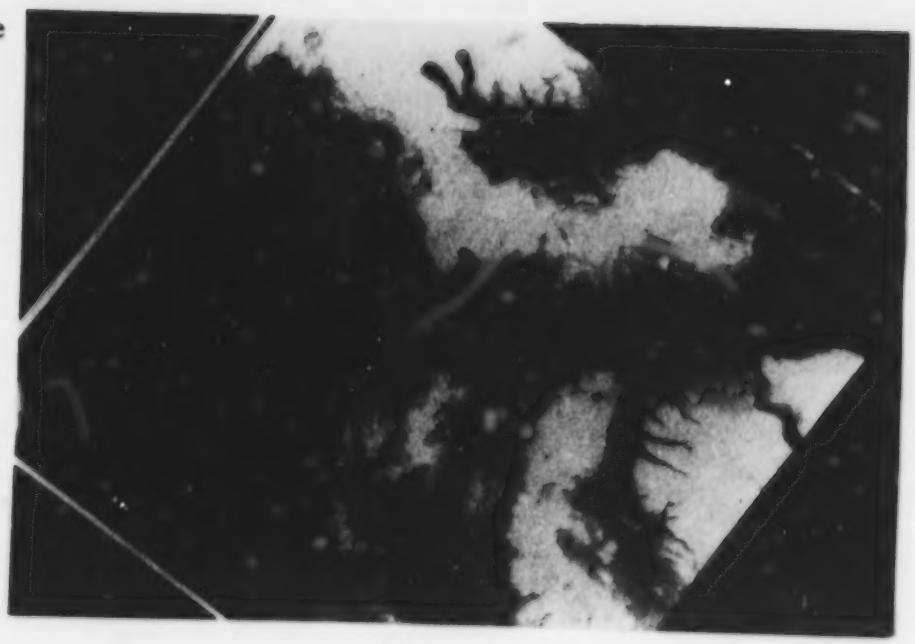
Figure 3.2 HRPT image and frame format

Figure 3.3: Comparison between APT and HRPT NOAA Images, October 28, 1986

APT Image



HRPT Image



Nonetheless, the move to the new POMS series later this decade for the reception of satellite images should be taken into consideration in the design of the G-2 ice navigation system.

3.1.2 GOES

The GOES (Geostationary Operational Environmental Satellite) consists of two geostationary satellites operating at an altitude of 35,800 km posted at 75 W (GOES - EAST) AND 135 W (GOES - WEST). The primary sensor on board the GOES satellite of potential use for ice studies is the VISSR (Visible and Infrared Spin Scan Radiometer). The VISSR is an eight channel scanner sensitive to the visual and thermal infra-red spectrum. Image resolution is nominally 4 to 7 km from the VISSR (Gibson, 1984).

Unlike the NOAA series of satellites, direct reception of real time images is not possible from the GOES satellites. The real time 28 mbps transmission from the GOES VISSOR is received by the NESS station at Wallops Island, Virginia. The data is geo-corrected, calibrated, annotated then re-transmitted back to the satellite (at a reduced rate of 1.8 mbps) for re-broadcast to users. Images are transmitted at half-hour intervals throughout the day.

The major limitation of GOES data to an ice navigation system is the lack of Arctic coverage (coverage is not available for region above 60° N) and the relatively low resolution of the sensor (compared to the NOAA AVHRR). However, the GOES satellites are an important source of weather information to North America and, as such, should be of great importance for a marine-based system for weather forecast on the east coast of Canada. As such, the ability to receive GOES images should be considered in a G-2 ice navigation system.

3.2 DMSP

The DMSP (Defense Meteorological Satellite Program) is operated by the U.S. Department of Defense (DOD) to provide global visible and infra-red cloud data and other specialised meteorological, oceanographic and solar-geophysical data required to support DOD operations worldwide (Heacock 1985). The DMSP system is similar to the NOAA-NESS operation and the satellites have similar orbital and sensor characteristics. The DMSP system consists of a series of satellites, ground stations and data processing systems including the direct receipt of data to tactical field sets (such as aircraft carriers at sea).

Unlike the NOAA system, which provides uncoded data to users, the DMSP system downlink is encoded and not available for civilian use. The encoded data greatly limits the utility of DMSP data for an ice navigation system. However, there is an agreement between DOD and NOAA for the sharing of data between the two organizations which has made data from the DMSP useful for ice studies and, therefore, the DMSP is a potential source of data for an ice navigation system.

There are two sensors on board the DMSP satellite of use for the remote sensing of ice, the OLS (Operational Linescan System) and the SSM/I(Sensor System Microwave Imager). These sensors will be described here.

3.2.1 DMSP-OLS

The OLS is a two channel optically scanning radiometer similar to the NOAA-AVHRR but configured for the special application of military uses. The satellite based processing and scanner configuration are such that automatic rectification and constant spatial resolution across the scan is achieved allowing for rapid turn around time for receiving stations. The OLS provides a higher resolution of .6 km than the AVHRR in two bands at visible .4-1.1 μm and infra-red at 10.2 - 12.8 μm. (Heacock, 1985).

The OLS is the primary sensor on board the DMSP providing images of cloud patterns in support of a wide range of military applications. The images have also been used for a number of sea ice studies which also have military applications. No APT type service is available from the DMSP with all downlink occurring in S band at 2252.5 MHz. Ground stations include central processing and tracking stations as well as portable tactical ground stations comprised of the entire receiving station (including the 3 metre parabolic antenna). The processing and re-transmission of satellite images to a wide range of military users via the WESTAR civilian communication satellite is undertaken by the DMSP central ground stations.

3.2.2 DMSP-SSM/I

The Sensor System Microwave Imager (SSM/I) is a scanning four frequency microwave radiometer passively sensing at 19.3, 22.2, 37.0 and 85.5 GHz. The first three frequencies are sensed at a resolution of 35 km and the 85.5 GHz frequency is sensed at 15 km resolution. Each frequency is sensed at both vertical and horizontal polarizations providing eight channels of data. Daily global coverage is provided from the 1,400 km swath width with repeat coverage every 12 hours in polar regions. (Weaver and Barry, 1985). The scan geometry of the SSM/I is illustrated in Figure 3.4.

The use of passive microwave data for sea ice remote sensing has been the topic of intense research over the past several decades, (NASA, 1984). Variations in the passively sensed electrical properties of sea ice with changing age and concentration over the various millimetre wavelengths has shown much promise in the ability to determine the distribution of sea ice over a region. To this end, the U.S. Navy sponsored the installation of the SSM/I on board the DMSP to aid in strategic determination of sea ice parameters (as well as other environmental variables) for defence purposes. It is expected that the SSM/I will provide ice concentrations accuracy to $\pm 12\%$ and ice edge location to ± 12.5 km (Heacock, 1985).

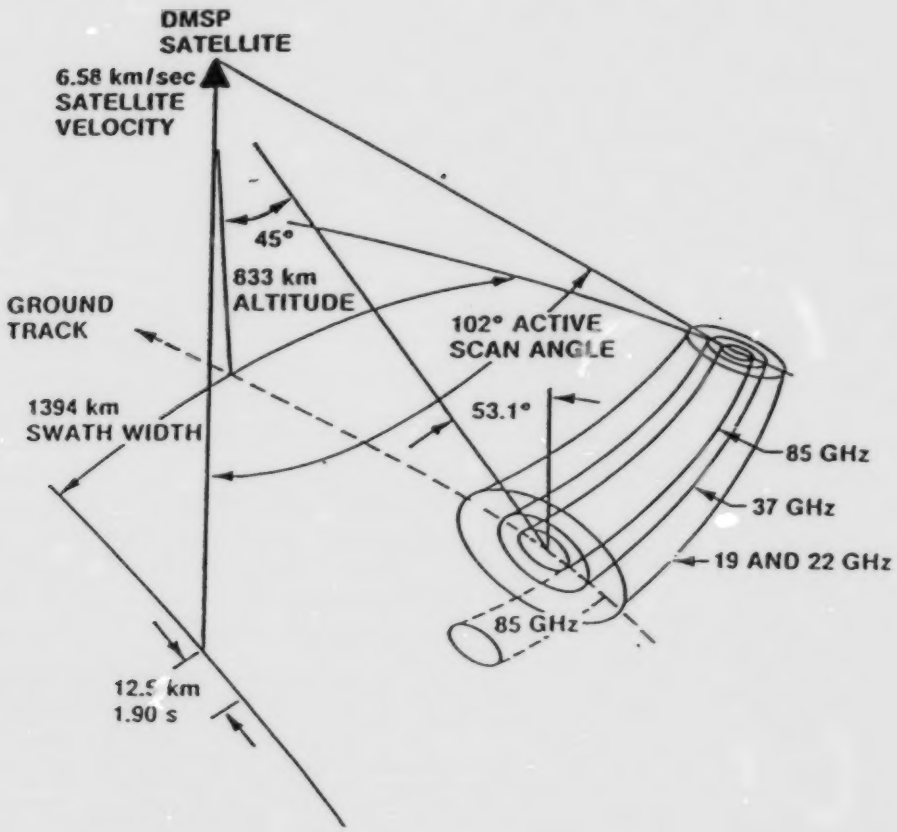


Figure 3.4 SSM/I Scan Geometry (Source: NASA 1984)

The SSM/I was launched on board a DMSP satellite, in June 1987, and the operational evaluation of the sensor for sea ice determination is ongoing. The data from the SMM/I is transmitted to one of the three DMSP stations which is subsequently linked to the Fleet Numerical Oceanography Centre (FNOC) and Air Force Global Weather Centre (AFGWC). At the FNOC and AFGWC, the engineering values are converted to equivalent antenna brightness temperatures. Unlike the OLS, the data from the SSM/I is available for civilian use. An agreement is in place between the DOD and Environment Canada for the operational transmission of SSM/I data to the Canadian Climate Centre (CMC) in Toronto (D. Lapp, pers. comm.).

SSM/I temperature brightness data is transmitted to the CMC where algorithms, developed by A.E.S., are applied to the data to discriminate first year ice from old ice and the ice edge. Contour maps and maps of point numerical values of the sea ice concentrations are produced by A.E.S., from the computer applied algorithms. These computer generated maps are accessed by Ice Centre, A.E.S., in Ottawa via a telephone modem link to the CMC. Data are usually available to Ice Centre four to eight hours after the satellite pass (D. Lapp, pers. comm.).

Although the operational evaluation of these data is still ongoing, initial results indicate that the data is of use to supplement NOAA AVHRR data when cloud cover is present (as clouds are relatively transparent to millimetre waves). These data have been found to be useful for the Labrador Sea ice edge, Baffin Bay and the Beaufort Sea as well as on a shipboard trial in the East Greenland Sea. Ice Centre has found that the determination of the ice edge location has been good but that the total and old ice concentration values are under reported from the algorithms. A major limitation of these data in the Canadian context is that data cannot be used if land is within 30-40 km. Therefore, SSM/I data cannot be used in northern Baffin Bay, the Arctic Islands and the Gulf of St. Lawrence, which are the major ice covered shipping channels for Canada.

The SSM/I sensor is planned to fly on subsequent DMSP satellites beyond the year 2000. Ice Chart - like data is available through modem access from CMC for a fee of approximately $400/month. Data can be received as a chart via either facsimile or read into a computer for video display and/or colour enhancement.

3.3 SOVIET SATELLITES

The Soviet Union operates a number of environmental satellites of interest to ice information users. The two satellite systems of interest for an ice navigation system are the METEOR and COSMOS systems. The Soviet Union relies heavily on navigation through ice to service ports along the Northern Sea Route of the country. As such, the Soviet Union routinely use the direct downlink of data from their environmental satellites to help in the forecasting of ice conditions for marine operations.

3.3.1 METEOR

The METEOR satellite system carries an array of sensors similar to the NOAA satellites. The sensor of interest to ice navigation systems is the MSU-M which is a multi-band radiometer similar to the NOAA AVHRR. The MSU-M is a four channel radiometer sensing in the .5 - 1.00 μm spectral band at a resolution of 1.7 km (Selivanov et al, 1985). An additional thermal infra-red (~10.0 μm) band has been identified recently from METEOR receptions on board the M.V. Arctic.

As part of an international agreement on the provision and sharing of meteorological data, the Soviet METEOR images are freely available in APT format as are the NOAA AVHRR transmissions. The known frequencies on which METEOR data are available on APT are 137.3, 137.4 and 137.85 MHz (Gorman and Sodowski 1986). However, unlike the NOAA AVHRR transmissions, which are duplexed with two bands transmitted at one time (see Figure 3.1), METEOR images are single-plexed with only one band transmitted at any one time. Therefore, although the MSU-M has a lower

resolution than the AVHRR (1.7 as opposed to 1.1 km) due to the single channel transmission, it has a higher APT resolution of 3 km as opposed to 4 km for the AVHRR. Canarctic has been receiving APT images from the METEOR satellite operationally since 1985. The visual band images have proven to be useful in the spring and summer (providing higher quality data than their AVHRR counterpart) but the thermal IR images lacked the definition of their AVHRR counterparts. Figure 3.5 is an example of METEOR visual and thermal IR images.

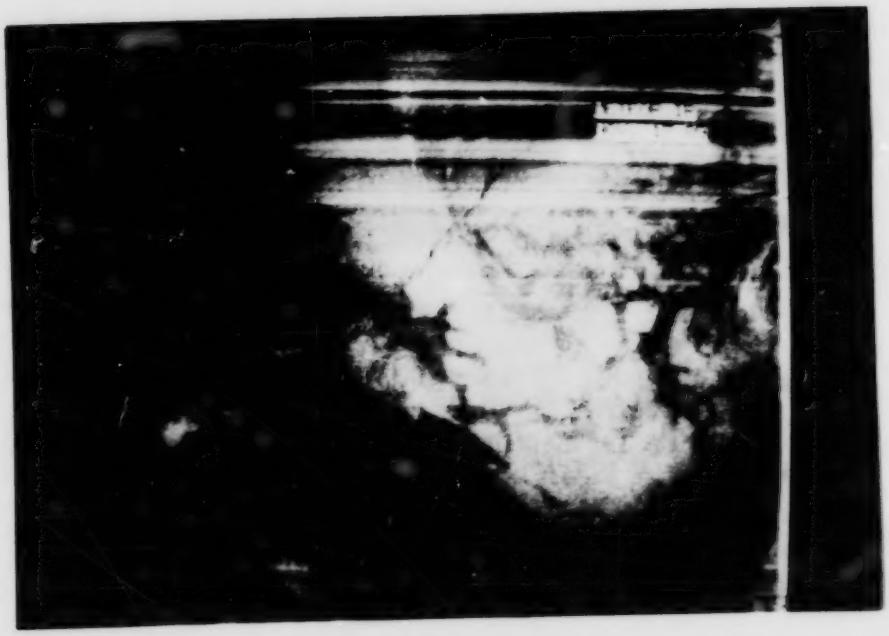
It is difficult to acquire detailed information on Soviet spacecrafts but it appears from the review of Soviet literature that there is no HRPT type downlink available from Soviet spacecraft. (Gidrometerozdat 1988).

3.3.2 COSMOS

Whereas the METEOR satellites provide visual and thermal infra-red data, the Soviet COSMOS series provide microwave band data. The primary instrument on board the COSMOS satellite is the Side Looking Radar (SLR). The SLR is a real aperture radar system operating in X band. The swath width of the SLR is 450 km providing a ground resolution of 2 to 4 km (Gidrometeozdat, 1988).

The transmission of data to earth is via an APT broadcast (Zehr, 1985) at 137.4 MHz. Figure 3.6 is an example of a film strip from the COSMOS SLR system over the eastern Beaufort Sea. The reception of SLR APT images could make a significant addition to an ice navigation system. Canarctic is investigating, through a Canadian consortium of companies (the Canadian Marine Transport Group), the possibility of obtaining the ability to receive Soviet satellite data in the west that can be useful for navigation.

Visual Band Image



Thermal Infrared Band Image

Figure 3.5 Meteor Visual and Thermal Infrared Band Images

Figure 3.6: COSMOS SLR Image of Eastern Beaufort Sea, November, 1988
Banks Island visible in bottom of image.

3.4 Radar Satellites

There are two radar satellites planned for launch in the early to mid 1990's that will provide microwave data of use for Arctic navigation, the ERS-1 and RADARSAT.

3.4.1 ERS-1

The European Space Agency's Remote Sensing Satellite (ERS) program will launch its first satellite in 1991. The satellite, ERS-1, will have a set of microwave instruments to measure the atmosphere, ocean and land. The principal instrument of interest to ice information users is the AMI (Active Microwave Instrument) which will be the first spaceborne SAR radar system since the failure of the American SEASAT L-band radar satellite in 1978.

The AMI will operate in C-Band (5.3 GHz) providing a ground resolution of 30m x 30m over a 100 km swath, offset from the spacecraft orbital track by 250 km (ESA 1988). On board recording of the SAR data is not possible with ERS-1, due to the data volume generated by the AMI (105 mbps) so all downlink will be via line-of-site X band frequency to the ground stations (located at Kiruna, Sweden, Fucino, Italy, Mas Palomas, Canary Islands, Gatineau, Canada). The data reception range from ERS-1 is 2,000 km diameter from each station with the radar able to operate for 10 minutes per orbit. The footprint from each receiving station will leave a large proportion of the Canadian Arctic uncovered by ERS-1.

It is planned that a fast delivery product will be available with AMI image data being available within 3 hours of the satellite overpass from the receiving stations. Once the SAR images are processed by the receiving stations, the images will be transmitted to users via the ECS/SMS communications satellite. The ECS/SMS is a European communications satellite whose foot print does not cover Canada. There are no indications at present whether a similar broadcast via communications satellite will be

available over Canada. Data will only be available to authorized members of the ERS-1 program. The Ice Centre, Environment Canada, is a member. Therefore, there remains the possibility that image products generated from the ERS-1 and received by Ice Centre, A.E.S. could be available for re-transmission to marine operations. The costs and associated logistics to undertake this will need development but high data rate communications satellite links would be required. Details on the ERS-1 ground segment can be found in ESA 1988 (b).

3.4.2 RADARSAT

RADARSAT is Canada's central remote sensing satellite initiative. The satellite, scheduled for launch in 1994, will have an expected life of five years. Data reception stations will be located at Fairbanks, Alaska, Prince Albert, Saskatchewan and Gatineau, Quebec.

Unlike ERS-1, RADARSAT will have full on board data recording ability of the 100 mbps data stream which can be re-played to ground stations when in range, providing complete global coverage. The primary sensor on board RADARSAT is a C-Band SAR (5.3 GHz) imaging mostly to the right of nadir. The radar power cells will allow for 28 minutes of SAR operation during a 101 minute orbital period with 15 minutes of on board recording capability.

The RADARSAT SAR will have five modes of operation. The SCANSAR mode will have a width of 300 to 500 km at a resolution of 50 or 100 metres. In WIDESWATH mode, the swath width will be 180 km with a resolution of 35 m. The STANDARD MAPPING mode will have a swath of 100 km at a resolution of 28 m. The FINE RESOLUTION mode will have a swath at 50 km and a resolution of 10 m. There will also be an EXPERIMENTAL BEAMS mode with a 100 km swath and 28 m resolution. This imagery mode variation will provide great flexibility to the application of the radar such that daily coverage of the Arctic is possible with RADARSAT.

The data acquisition, processing and distribution system will be based on those developed for ERS-1. The on board data handling system will contain two X-band downlink channels capable of operating at 100 mbps on the 8.215 to 8.4 GHz band. One channel will be used for the downlink of real time data and the other for transmission of recorded data from tape replay. Both channels can operate simultaneously (Ahmed et al undated).

Downlinked data, received by the ground station, will be re-transmitted via the ANIK high data rate communication link to the central processing centre in Ottawa. Processed SAR images will then be re-transmitted via ANIK to users with the data turn around time expected to be approximately four hours. (Ahmed et al undated).

The recast of RADARSAT data for shipboard use via the ANIK link could provide a valuable strategic information source for SINSS.

3.5 Airborne Microwave Imagery

The reception of airborne radar imagery on board a vessel has been identified as a critical component of an ice navigation system (Canarctic, 1985). There are three aircraft systems available in Canada today which routinely transmit radar data to vessels for ice navigation. Two of these aircraft are flown by or for the Atmospheric Environment Service (A.E.S.) for ice reconnaissance (DASH-7 Canice 3 and Challenger Canice 5) and one flown for private contract purposes (Intera STAR-1).

3.5.1 DASH-7 SLAR

Routine ice reconnaissance is undertaken by Ice Branch, Environment Canada, using a modified de Havilland DASH-7 aircraft, fitted with a Canadian Astronautics Ltd. (CAL) SLAR-100 system. The aircraft has been designated CANICE 3 by Environment Canada. The CAL SLAR-100 is a real aperture radar system designed to operate from

an altitude of 1,000-9,100 metres. The radar is dual sided with swath widths selectable between 50 or 100 km. Additional navigational and latitude and longitude information are embedded within the SLAR data by an add-on data processor (SSC, 1986).

Real-time downlink of SLAR imagery is available from CANICE 3 on an S band (2.3 GHz) downlink transmitter. The SLAR imagery from the CAL-100 SLAR is formatted in to a 700 kbps data stream which is passed through a convolution encoder which increases the rate to 1.4 mbps for transmission to the surface vessels. The received data is reduced from 1.4 mbps to 700 kbps by the ship-based receiver. The SLAR imagery has a format of 5,360 pixels/line of 200 km total width. Both the right and left sides of the SLAR radar data are embedded in the transmitted line, along with the offset gap between the two sides centred at nadir. The SLAR image line spacing is dependent on the aircraft speed and will typically be 16.5 metres with an azimuth resolution of 20 metres in the near range and 780 metres in the far range. Each incoming data line must be positioned in the imagery using the aircraft speed information contained in the annotation block of each line in order for the image to be re-constructed.

Canarctic's experience with using SLAR has been that the data is not of sufficient quality for the tactical requirements of SINSS but is of use for strategic planning purposes. (Canarctic, 1985).

3.5.2 CIRS Challenger SAR

A.E.S. entered into a contract with Intera Technologies Ltd. of Calgary, Alberta, for the provision of a Comprehensive Ice Reconnaissance Service (CIRS). There are two components to this system comprised of an airborne ice reconnaissance system and surface based data reception and processing facilities. The ship based system consists of the Intera STAR-VUE system, an element of the first generation SINSS which is to be replaced by the G-2 system. The airborne system is comprised of a Challenger jet fitted

with two MacDonald Detwiller and Associates (MDA) IRIS SAR systems and associated downlink hardware.

The two SAR systems provide the aircraft with a dual sided imaging capability with selectable swath widths of 50 or 100 km for each side. Any combination of 50 and 100 km swath widths may be selected by the operator. The imagery is presented in a format of 4096 pixels wide, at a resolution of either 15 m (50 km swath) for high resolution, or 25 m (100 km swath) for standard resolution mode. The transfer data rates are relatively high and the images from one mission will typically occupy 350 M bytes of data storage corresponding to 4 or 5 flight lines. Data is communicated to the vessel via an S band downlink at 2.3 GHz. The data is passed through a convolution encoder (similar to the SLAR-100) which increases the rate to 1.4 mbps which is then transmitted to the vessel. On board the vessel, the STAR-VUE receiver converts the 1.4 mbps downlink to 700 kbps. During a voyage, up to four missions may be flown, for a total of 1.4 giga bytes of data.

SAR has been found, during the SINSS development program, to be a critical data source for ice navigation.

3.5.3 STAR-1

The STAR-1 (Sea Ice and Terrain Application Radar) is the predecessor to the CIRS Challenger SAR described in Section 3.5.2. The STAR-1 is flown is a Cessna Conquest turbo prop aircraft at operating altitudes between 17,000 and 33,000 feet. Data is single sided, selectable to either side of the aircraft at either narrow swath (23 km) or wide swath (46 km) mode. Pixel resolution is 6 x 4 metres in narrow swath mode and 12 x 4 metres in wide swath mode. Each line of data contains 4096 pixels at 8 bit resolution.

The downlink of data is provided via a 219.5 MHz transmitter operating at 280 K bits/sec. Due to bandwidth limitations, the resolution of the narrow swath data is reduced to 12 metre square pixels and the wide swath data to 24 metre square pixels for the downlink. It should be noted that a special licence is required to operate the downlink as the 219.5 MHz band is not normally allowed for the transmission of this type of data in Canada.

3.5.4 AIMR

The Atmospheric Environment Service owns a passive microwave radiometer called AIMR (Airborne Imaging Microwave Radiometer) built by MPB Technologies of Montreal. The AIMR operates on the same principles as the SSM/I in that the radiometer passively sense naturally emitted microwave energy. The AIMR is a dual frequency radiometer sensing at 37 and 90 GHz in both vertical and horizontal polarization providing four channels of data. The AIMR was designed to be carried on board the A.E.S. Ice Reconnaissance Electra aircraft CANICE 1. The system has been installed and tested but the aircraft is now no longer on contract to A.E.S. The system will not fit on either of the two remaining aircraft (CANICE 3 DASH-7 or the CANICE 5 Challenger) so its future as an ice reconnaissance sensor is uncertain.

The AIMR resolution and swath width are variable according to the altitude of the aircraft. At 900 metres the resolution of the sensor is 38.5 m at 37 GHz and 16 metres at 90 GHz over a swath width of 3 km. At 4,500 metres, the typical operating altitude of the CANICE 3 SLAR aircraft, the resolution of the AIMR is degraded to 189.5 metres at 37 GHz and 80 metres at 90 GHz but at a wider swath of 14.4 km. At the operational altitude of the CANICE 5 Challenger jet of 10,000 metres, the resolution of the AIMR is 420 m at 37 GHz and 175.5 m at 90 GHz over a swath width of 32 km.

A provision has been made for the AIMR to be adapted for a downlink but this has not, as yet, been implemented. If a downlink were to be added to the AIMR, it is

possible that the data stream would be added to the existing S band stream used for the SLAR/SAR downlink. Data are recorded on board the aircraft onto a tape recorder as well as displayed onto a soft copy video monitor for analysis. Data collected on board the aircraft is further analyzed on the ground after the plane has landed to produce map and image products. (Harrison 1987).

The AIMR will image the area directly under the aircraft not imaged by either the SLAR or SAR. Initial results from the field trials of the AIMR were very encouraging and the sensor showed great potential to discriminate ice types. Information from the AIMR would provide a valuable input to a shipboard ice navigation system. Unfortunately, the lack of an aircraft to fly the sensor and the lack of a downlink capability will make this sensor unusable for ice navigation indefinitely. Hopefully, these problems may some day be rectified so that the sensor could provide data to the G-2 system.

3.6 Ship-based Sensors

These are three shipbased sensors currently available or under development which can be used as input to an ice navigation system; Arctic Marine Radar, SONAR and Ship-based Radiometer (SBR).

3.6.1 Arctic Marine Radar

By far the most important and used sensor for the detection and avoidance of ice by ships is the marine radar. Volumes could be written on the application of a marine radar to ice navigation and on the diversity of systems available to do the job. It is not the intent of this section to detail all the possible combinations of radars available to undertake the ice navigation function. Canarctic has initiated the development and installation of a marine radar specifically suited to navigation in ice. The reader is directed to Gautier, (1990 a) for details on Canarctic's Arctic Marine Radar Program. In

this section, the source of data from the Canarctic Arctic Marine Radar System will be described.

The Arctic Marine Radar installed on board the M.V. Arctic is based on a modified SPERRY RASCAR radar. The RASCAR was selected as the host radar due to the modular nature of the system components which allows for the modification of operating parameters. The RASCAR is an X band radar with a transmitted power of 50 KW and a low noise front end amplifier providing a logarithmic signal with negative polarity. The transmitter transmits RF pulses of a minimum of 75μs duration at a maximum repetition rate (Pulse Repetition Frequency) of 2,910 Hz. The video signal has a bandwidth of 6 MHz at an amplitude of 2 volts peak.

In addition to the RASCAR transceiver, a C.H.L. dual polarized (Horizontal and Vertical), antenna was used. Two transceivers were connected to the C.H.L. antenna, one transceiver transmitting and receiving on the horizontal (HH) channel, while the other transceiver is used to receive only on the vertical (HV) channel. The two outputs are simultaneously available as separate channels.

Future developments with the Arctic Marine Radar will see refinements to the antenna speed, PRF, pulse width and power to gain the optimal performance in a given ice condition. Maximum video bandwidth in the order of 20 MHz and PRF reduced to 1.5 KHz are some of the envisaged operational limits.

The marine radar has been a critical source of tactical and near range ice information as part of SINSS and will form a critical link in the G-2 system.

3.6.2 SONAR

The modification and testing of a forward looking fish finding SONAR for ice detection was undertaken on board the M.V. Arctic in 1985 and 1986 (de Heering et al,

1985, de Heering, Sutcliffe, 1987). The results of the tests indicated that detection of icebergs from .5 to 1.0 nautical miles ahead of the vessel was achieved. A range of up to 5 nautical miles resulting from hardware improvements and the use of a dual frequency SONAR may be achievable. Since a SONAR has not, as yet, been developed that could be specifically suited to ice detection, no specifications are available. However, it is expected that any system developed will be interfaceable to the G-2 system.

3.6.3 SBR

The Ship Based Radiometer is under development by A.E.S. and a prototype version built by COM DEV of Cambridge, Ontario, has been field tested. The SBR is a passive microwave radiometer sensing at 36 GHz in vertical and horizontal polarizations at a beam width of 2.4°. The radiometer is designed with a single horn which is mechanically moved in a grid pattern scanning in front of the vessel. It takes approximately five minutes for the SBR to construct an image. Early work with the SBR indicates that the unit has a maximum range of approximately 100 m. Given that the image is produced in five minutes, the technology has limited use for tactical navigation at this time. However, future developments with the SBR may increase the range to 500 metres, and reduce the time required for image construction.

The output from the SBR is displayed on a colour screen and the data analysis is undertaken on PC compatible computer equipment. Future SBR should be easily interfaced to the G-2 system should future developments prove its value as a ice detector system.

3.7 HF Transmissions

The reception of ice information over the HF radio band has traditionally been the most important source of externally acquired data for a ship navigating in ice. The reception of ice and weather charts via marine facsimiles often is the only means (outside

of direct communication satellite li..s) to transmit information at a range beyond line-of-sight to a ship. The source of HF Ice information in Canada is the Ice Branch of the Atmosphere Environment Service, Environment Canada.

Ice Branch is responsible for the collection and reporting of ice conditions of significance to shipping in Canadian waterways. The products received on a regular basis for shipboard use are the Observed Chart and the Ice Analysis Chart. Other products are produced by Ice Branch, such as seasonal forecasts and telex messages on ice conditions, but these do not impact on the design of a G-2 ice navigation system.

3.7.1 Observed Ice Chart

The Observed Ice Chart is produced by a Government of Canada trained ice observer stationed on board either an ice reconnaissance aircraft or Coast Guard icebreaker. Only one of the two aircraft flown by or for A.E.S. carries ice observers, the DASH-7 CANICE 3. The Observed Chart is a composite of both the interpretation of SLAR images and observed ice conditions from the aircraft. Observed charts are produced at a scale of 1:1 million and are the largest scale of any chart produced by A.E.S.. Ice coding terminology used in the reporting of ice conditions follows an international standard defined by the World Meteorological Organization (WMO) and is described in MANICE (1989).

Observed Ice Charts are broadcast each hour via HF to Ice Centre in Ottawa. The frequency used is usually 15642.1 KHz, upper sideband mode. The transmission of a chart from the aircraft to a ship is usually done on 4616.0 or 6915.1 KHz. Other frequencies may be used depending on HF propagation conditions and include 8113.1, 10155.1, 10169.1, 12055.1, 13440.1, 14624.6, 17443.1 or 18168.1 KHZ.

Although Observed Charts are received with standard paper-fed facsimile machines at the moment, the option exists with the G-2 system to have the charts digitized and

overlaid on other ice information (such as satellite images) for strategic planning purposes.

3.7.2 Ice Analysis Chart

The primary operational product of Ice Forecasting and Analysis, A.E.S., is the Ice Analysis Chart. These charts represent a synoptic analysis of ice conditions to be encountered over a selected water body and follow standard international ice reporting codes as defined by MANICE (1989) and are issued at a scale of 1:2 million.

An Ice Analysis Chart is produced by an ice forecasting meteorologist based on satellite, ice reconnaissance and meteorological information. Existing ice conditions recorded or observed chart and interpreted from NOAA and LANDSAT satellite images are combined with forecast wind and temperature data to produce an Ice Analysis Chart. The chart is transmitted, via telephone facsimile, to Coast Guard marine radio stations for broadcast to surface vessels via marine HF radio facsimile. Table 3.3 lists the Canadian Coast Guard Stations and broadcast frequencies used for the HF transmission of Ice Analysis Charts.

Table 3.3
Broadcast Schedule of Ice Analysis Chart

Broadcast Station	Broadcast Frequency (Khz)	Time (UTC)
VFF Iqaluit	3251.1/7708.1	20:00/23:35
VFR Resolute	3251.1/7708.1	14:30/23:04/01:00
CFH Halifax	4271/6330 10536/13510	00:14/11:01/13:01 14:01/22:01/23:01

An Ice Analysis Chart provides less detail than an observed chart but covers a much wider area and the availability of the chart is not limited by the presence of an ice reconnaissance aircraft. As with Observer Charts, the ability to digitize received Ice Analysis Charts for overlay on other ice information could be an element of the G-2 system.

3.8 Communications Satellite Link

The transmission of ice information via satellite link may play an important role in a G-2 ice navigation system. No other long-range communications channel offers the reliability of transmission, the channel bandwidth combined with Arctic coverage. HF radio links are dependent on atmospheric conditions and are bandwidth limited. The amount of ice information available now and in the near future, particularly with the new A.E.S. Expanded Ice Information Services Program, may lead to the establishment of communication channels to transfer these data to ships and communications satellites appear to be the logical choice. The transmission of SAR products such as aircraft mosaics or ERS-1 and RADARSAT images would be valuable input to the ice navigation system.

There are two communication satellites available for such transmission, INMARSAT and ANIK.

3.8.1 INMARSAT

The INMARSAT (INternational MARitime SATellite organization) network of satellites provide global (except for extreme polar regions) coverage for telex, voice, data and facsimile services. All these services are accessed through a shipboard stabilized dish antenna of no more than one metre in diameter. Operating since 1982, the INMARSAT service provides communications in two standard station configurations; standard-A and standard-C.

Only the standard-A station is of any interest to the G2 system, for the purpose of transmitting images to Arctic going vessels. The standard-A station offers data rates similar to those available on standard telephone lines. Therefore, data rates higher than 9,600 band are not considered feasible specially in the higher latitudes. Experience on the M.V. Arctic has shown that INMARSAT coverage does not extend reliably beyond 80°W longitude, and 74°N latitude. In addition, the transmission costs over this service are typically $10.00/minute. At the above stated data rates, the required imagery would require at least 2 hours, resulting in a cost of over $1,200.00 per transmission.

3.8.2 ANIK D

The Anik D satellites operate in C band and are the only satellites with a foot print wide enough to cover the Arctic area up to latitudes of 78° or more depending on the equipment used. Even though most of the Arctic region is covered, certain areas where coverage is required are considered marginal and compromises must be made to ensure operation of the system in all conditions and trading areas.

A trade-off must be reached between the following elements:

1) The size of the receiving antenna must be increased when operating in the upper latitudes and eastern regions (along the coast of Greenland).

2) As the size of the antenna is increased, it becomes more difficult to accurately point the dish because of the reduced beamwidth.

3) The size and cost of a shipboard antenna are limited, and a limit has been set at 2.5 metres.

4) High data rates require large bandwidths and more power. High power and bandwidths cannot be accommodated with small antennae and, therefore, the 2.5 metre antenna size is limited.

5) Large bandwidths and high transmitted power cost more but require less time to complete the transmission. However, as a general rule, the lower data rates cost less for a given amount of data to be transmitted.

After discussions with Telesat Canada, it would appear that transmission rates of 19.2 kilobytes per second could be accommodated throughout the Arctic regions, using a stabilised 2.4 metre antenna. An analysis of the possibilities is currently being made, with results expected by the end of August 1990.

At the above discussed data rates, SAR images covering the entire Arctic area, including Baffin Bay, at a resolution of 200 metres/pixel, could be transmitted in less than an hour. Under these conditions, daily coverage of the Arctic could be broadcast by the ice centre to all ships equipped with a satellite receiver.

4. Functional Description

This section describes the various functions performed by the G-2 system. The various functions have been grouped under five headings for clarity and pertain to operations that must be performed in relation to a data source or a specific navigational requirement. Individually or in combination with each other, the system functions implement the ice navigation requirements described in Section 2 of this document.

4.1 General Functions

The general functions are those that may be used by more than one operation and are therefore not specific to an application. In addition, the general functions include those that are not used for any particular ice navigation process, but are required for general maintenance or for auxiliary applications.

4.1.1 User Interface

The user interface is one of the most important components of the new navigation system and will be given a high level of priority. The user interface should be highly intelligent and be capable of compensating for user errors or command ambiguity. Extensive on-line help messages and explanation menus should complement the user interface. User assistance should be context dependent and provide the best emulation of the system's awareness of what the user is attempting to accomplish. The complexity and level of on-line help should be selectable depending on the familiarity of the user with the system. Expert system techniques will be used to implement the assistant part of the user interface.

The full complement of input devices will be available for use on the system including track balls, joy stick, touch screen, virtual space devices, light pen, etc. Through these various interfaces, the user will interact with the system and control the application

currently running. Feedback to the operator of the actions and responses initiated by the system will be provided through video screens, audio messages, and recognisable system actions.

The user interface will be implemented in a menu structure. The menu structure will reflect the application it is meant to control, and the tasks to accomplish within the application. A facility will exist to show the user's current position within the menu structure. A facility will exist to bypass the menu structure and move from one menu position to another without having to backtrack through one menu branch and move down another. The menu structure will be accessible through a full screen window system, a side bar selection menu, or a terminal text interface. The selection of the interface style may depend on the user's choice, the nature of the application, or the necessity to keep the displays as free as possible.

The speed at which the system responds to a particular command is mostly related to system performance specifications. However, the user interface aspect of this response sets a maximum acceptable delay. In all cases, the system's acknowledgement of a command should be immediate. The execution of a command, depending on the complexity and the nature of the task, should begin no later than two seconds from command acknowledgement. All tasks associated with image aspect such as zoom, pan and line trace, should be executed in real time (with no noticeable delay). The system should keep the user informed of any ongoing process and should display the level of completion of this process.

4.1.2 Utilities

The system utilities can be grouped under software utilities and hardware utilities. Software utilities include such features as system's diagnostics, text editor, file maintenance utilities, training and simulation aids etc.. Even though the system is primarily meant to be a navigation tool, general purpose utilities should be included to

allow the proper maintenance of the system and its operation as a powerful computer instead of a dedicated image processor only.

The system will be equipped with high quality image printing capability. The capability to print high quality images should be put to good use by allowing to print video images recorded with high definition electronic cameras. This facility will, among other things, facilitate voyage documentation, allow the satellite transmission of on site images to head office, help document accidents and other important events.

Hardware utilities include such devices as text/graphics printer, graphics plotters, and any other output or entry device that is not directly linked to ice navigation. Such devices will allow to make full use of the system while not being used for ice navigation.

4.2 SAR Processing

This section will describe the various data handling and processing functions associated with the SAR imagery.

4.2.1 Data Reception

The system will allow the reception of SAR images with the least amount of interaction from the operator. Details such as flight line orientation, positions of start and end of line, data file name, SAR mode (wide or narrow swath) should not be necessary to initiate the reception of data. The specifics of the received data should be modifiable before, during or after the data have been received.

All SAR data manipulations, other than analysis and enhancement, will be executable concurrently. The user should be able to display and manipulate the imagery as it is being received on the system and at the same time produce a hard copy of the incoming data.

4.2.2 Image Enhancement

As received from the aircraft, the SAR image can be used for two purposes:

a) Visual interpretation of ice types and concentration
b) Correlation to the radar imagery

Performing these two tasks can be facilitated by suitable enhancement of the image. The two tasks being in opposition, the same enhancement cannot be used for both. In addition, enhancement for correlation will be different depending on whether the correlation is done visually or by the system. Therefore, at least three enhancements will be required for the SAR imagery:

a) Visual interpretation enhancement
b) Visual correlation enhancement
c) Computer correlation enhancement

For each enhancement required, various algorithms or techniques are possible. Algorithms for this purpose are being developed under a TDC program called "ALGORITHMS-ENHANCED RADAR IMAGES".

4.2.3 Mosaic Production

During ice navigation, it will often be necessary for the operator to cross from one SAR flight line to another. Since the flight lines have not been taken at the same time, ice movements preclude the use of absolute coordinates to find the ship's position on the new line. The vessel's position on the new line must be found using recognisable features from the two lines.

In order to facilitate this process, the flight lines should be digitally merged into a large mosaic that covers the entire SAR mission. In addition to facilitating the transition from one line to another, the mosaic allows to plot courses that straddle two lines, something that is difficult to accomplish accurately if the lines are not connected. The correlation of the radar map to the SAR imagery will be greatly simplified by the production of the mosaic and the accuracy of the correlation will be increased.

4.2.4 Interpretation Aids

The idea has been advanced that in some cases, interpretation software might be useful to assist the user in the determination of ice types and the associated threat to safe advance. In addition, the usefulness of SAR imagery may be increased by correlating it with other sources of information such as local ice thickness samples, satellite imagery (surface temperature infra-red images), or visual feature recognition. The interpretation aids will range from the simple enhancement techniques to the full expert system implementation.

4.3 Radar Processing

Probably the most intensive application in the G2 system is the processing of the radar signal in real time. The processing of the radar signal will be made in two steps:

a) The first step will consist of all the processes that precede and include scan conversion. These processes will include analog signal conditioning, signal digitization, azimuth alignment, azimuth processing and scan averaging techniques.

b) The second step will include image processing, mapping, and all other processes that use a cartesian image as an input.

The above two steps will most likely be implemented in different modules of the G2 system. The following sections describe the processing involved in both steps.

4.3.1 Radar Azimuth Processing

The production of the radar map is relatively straight forward in principle, and the benefits of its implementation are numerous. However, the usefulness of the mapping process is limited by the low resolution obtainable at far range (3 to 6 nautical miles) from standard marine radar equipment. At a range of 6 nautical miles and an antenna beamwidth of 1.2° for example, the radial resolution of the radar image is lower than 230 metres. This effect gets progressively worse as the range is increased. The net effect of the low resolution is a radial smearing of the image at the periphery.

If the mapping process is to be successful in providing accurate and high quality images for correlation purposes, some process has to be worked out to increase the resolution at far range. Several possibilities exist to achieve that result, and these are discussed further in Appendix C.

4.3.2 Digitization and Scan Conversion

The radar data acquisition module in the G2 system will have to perform several tasks before transmitting the radar data to other parts of the system. It will be the task of the acquisition module to produce image data that can be used by other processes such as mapping or HH/HV processing (refer to Section 4.3.4).

The acquisition module will perform the following tasks in order:

a) The radar signal will be processed through analog circuitry to format it for digitization.

b) The data will be processed to implement scan to scan integration, far range resolution increase, azimuth correction and other processes that require radial formatted radar data.

c) Perform scan conversion of the processed data and prepare it for transmission to other parts of the system.

The above processes are described in detail in Appendix D.

4.3.3 Radar Controls

Recent research (Gautier, 1990 b, Gautier, 1990 c) and the nature of the processes proposed for the G2 system, lead to conclude that precise and independent control of the radar operating parameters is necessary. Parameters such as video gain, STC (Sensitivity Time Control) curve, PRF (Pulse Repetition Frequency) and radar pulse trigger azimuth, are examples of what the G-2 system must control. Control of the radar operational parameters should be closely linked to the digitization process. Therefore, radar controls should be located in the radar data acquisition module. The exact nature and extent of radar parameter control is discussed in Appendix E.

4.3.4 HH/HV processing

A feature of the Arctic Marine Radar System, is the availability of two correlated signals generated from the dual polarized X-Band radar antenna. The signals from the two channels convey different but related information. The two signals are meant to provide information that will assist the operator in the identification of hazardous ice. Various techniques are under development, notably under DFO sponsorship, to combine the two signal sources and produce an image where hazardous ice is enhanced. Further discussions on HH/HV processing can be found in Appendix F.

4.4 Navigational Operations

The near totality of the functions performed by the G2 system will be implemented in support of the navigation process. This section describes the various navigation processes that will be supported by the system.

4.4.1 SAR Correlation

The SAR/radar correlation is one of the most vital tasks that will be implemented on the system. This task is the result of many primary processes, that make available at a higher level, the information necessary to its implementation. This section describes the primary processes required for the implementation of the SAR/radar correlation and its impact on the navigation process.

4.4.1.1 Mapping

Mapping refers to the construction of a high resolution shipboard radar image not restricted to the normal radar range but based on the accumulation of historical radar data. The construction of the radar map is made possible by the fact that the ice environment that necessitates the mapping process is relatively static and, therefore, allows the appendage of successive image sections to the base map. The map will be built up as the ship moves forward through the area to be mapped. Once built, the radar map will be processed to extract features that are recognisable on the SAR imagery. An electronic overlay of the extracted features will be generated (a kind of transparency with the outline of the extracted features) and transported over the SAR imagery where it will be visually aligned with recognisable features. Since the position of the ship is known relative to the radar map, the position of the ship relative to the SAR imagery will also be known. Further discussions on the radar map can be found in Appendix G.

4.4.1.2 Enhancement

The primary purpose of enhancing the marine radar image, is to bring out the features that will be used to correlate it with the SAR imagery. Several techniques have been developed so far, to extract various classes of features (ice floes, ridges, leads, icebergs, etc.). These techniques are still being developed under a TDC sponsored program called "ALGORITHMS-ENHANCED RADAR IMAGE" (Cimmetry Systems, i.p.). A variety of techniques are now available for implementation in the G2 system.

Secondary to the correlation process, other enhancement techniques will be used to improve the visual quality of radar images used for hazard detection and general purpose navigation. Appendix H describes further the various enhancement techniques.

4.4.1.3 Correlation

Once the radar map has been constructed and the feature extraction process has been carried out, the radar map overlay must be matched to the SAR imagery. Three variables must be known to perfectly match the overlay to the SAR imagery: the position, the orientation, and the scale of both the SAR and radar overlay. Since the scale is well defined for both the radar and the SAR images, translation and orientation are the only variables to resolve. The process will be carried out manually using the normal entry devices such as the track ball, joystick, and others. Since the ship's position is known relative to the radar map, it will be shown on the overlay. Once the overlay position has been correlated to the SAR imagery, the ship's position will automatically be known on the SAR imagery and route planning can be carried out. Updating the ship's position on the SAR imagery should be relatively straightforward since the radar map overlays will be produced frequently during transit. Frequent overlays mean that the new ship positions will be close to previous ones, and that very little searching will be necessary to match the overlay to the SAR imagery.

4.4.2 Display Orientation

Whatever the operation mode of the G2 system, i.e., open water, partially covered waters, full ice cover, the radar display orientation must be adapted to the task. For example, open water hazardous ice detection might be easier for the navigator if the radar display is oriented ship's head up. Conversely, when the ship is navigating in full ice covered waters, the displays would be better dealt with in the north up orientation for both the radar and the SAR imagery. In other situations, it might be beneficial to orient the radar imagery according to the SAR imagery orientation. Full control should be given to the user of the orientation of all images that can be displayed by the system. The orientation should not have any bearing on the real time nature of functions such as zoom and pan.

4.4.3 Georeferencing

There are two position components while navigating through ice. The first component is the ship's position relative to the ice surface, while the second component is the absolute position of the ship (relative to land masses, or georeferenced). Both positions must be considered independently since features in the ice surface and around land masses must be avoided simultaneously (see Section 2). However, in most cases, absolute position is secondary to relative position in the process of ice detection and avoidance.

At any time, the absolute ship's position can be determined using a variety of instruments such as the Loran, the Satnav, the radar, etc. Once the ship's position has been determined relative to the SAR imagery, the position of the SAR imagery can be monitored and the drift calculated. The updated absolute position of the SAR imagery can then be used to plan a route in areas where both relative and absolute positions are necessary. The G2 system will have facilities to assist the operator in this process.

4.4.4 Projected Radar Image

While the ship is navigating in ice covered waters, one of the many tasks supported by the system is close range (less than 1 nautical mile) ice hazard detection. A difficulty arises when detected targets come within the .25 nautical mile range on the radar display. The strength of the radar signal, interference from the ship's front structures, receiver circuit non linearity, all contribute to complete loss of target at very close range.

As in cases where radar mapping applies, the ice environment must be static for this process to apply. In order to resolve the close range display problem, it is suggested that the radar image collected at a range of between .5 and .75 nautical mile or so ahead of the vessel, be used to display the ship's position. The ship's position will be shown at the centre of the display (as in conventional displays), surounded by a radar image that will have been collected earlier but has not changed since. At a vessel speed of 5 or 6 knots, the delay would be less than 6 minutes. In a static ice environment, no change would occur in such a short time. The navigator will operate the radar as if it were displaying real time data, with much improved image quality.

4.4.5 Automatic Tracking

Once the facilities exist to manually correlate the radar image to the SAR image, it would seem reasonable to attempt to automate the process, leaving the system to deal with updating the ship's position on the SAR imagery. The main difficulty resides in the fact that features extracted from both sets of images will never be equivalent except in very rare cases. A feature that is extracted as being a lead in the radar image, may turn out to be the interface between two ice floes. Enhancement techniques developed for visual correlation may not be adequate for automatic tracking.

Enhancement methods must be found for each image, that will yield the same type of extracted features. These features will then be easier to correlate with a reasonable

level of accuracy by the computer system. It is one of the goals of this system to attain a level of automation such that the navigator is left with the only tasks of verification, route planning and hazardous ice avoidance.

4.4.6 Annotation Aids and Plotting Functions

In order to assist the navigator in the tasks of route planning, target avoidance or narrow geographic passages, a number of annotation and tracing facilities must be available on the system. The system must be capable of tracing the exact ship's route on the SAR imagery as it advances. Full annotation of the displayed images (from any source) on a temporary or permanent basis must be possible. The user must be capable of shading certain areas to be avoided for example, or simply insert text at specific locations on the images. Full support for course, distance, range and bearing measurements and plotting must be accessible, as well as full editing functions for same. Distances and directions should be available in all customary modes and measurement units, nautical miles, pixels (if needed), metres and multiples thereof, feet, yards, statute miles etc, relative or absolute coordinates and from any reference point.

Distances and other parameters along various route scenarios should be automatically calculated on request. For example, two routes might seem advantageous and have been plotted on the imagery. The user would select a route and the system would display relevant information such as expected transit difficulty, estimated time to destination, and total distance to travel. The system should handle several possible routes simultaneously and retain them in memory for instant recall. The user will be able to attach memos to certain points along the route. These memos will not be displayed normally but will be represented by a special symbol on the imagery which can be selected to view the memo.

4.4.7 Cross Linking

The G2 system is intended to be used for other applications than strictly navigating in ice. One possible application will be the management and early warning of ice conditions for fixed platforms. Drill ships typically use the same kind of information for ice management that ice breaking ships use. Consequently, it is possible that the same equipment be used for ice breakers also can be used to monitor and manage the imagery for drilling platforms. The major difference resides in the frequency and accuracy of the ice information required for both applications.

In the area of G-2 application for fixed platforms, ice movements rarely exceed a speed of 5 knots, and the range at which ice information is required is limited to approximatly 50 nautical miles (Capt. P. Mowat, Beaudril, pers. com.). Under the new AES (Atmospheric Environment Services) EIISP (Expanded Ice Information Services Program), SLAR and SAR missions are regularly flown, both in the eastern and western Arctic regions. However, western missions over the Beaufort sea are predominantly SLAR missions. SLAR imagery has been determined, by Canarctic, to be marginally acceptable for ice navigation, due to the relatively low resolution of the imagery. Conversely, SAR imagery provides the required resolution but is not routinely available over the Beaufort sea during the drilling season.

A strategy was imagined to complement the available information without having to resort to more frequent SAR missions, yet obtain timely information of comparable quality. The drill platforms are usually serviced by a number of supply ships that could be equipped with a G2 system. Each supply ship would travel once a day in the area to be monitored and build a local radar map of the immediate environment. The constructed radar maps would then be radio-linked to a central station (drill platform) where a mosaic would be assembled. The resulting mosaic would be used to update and extend the useful life of SAR imagery and provide detailed imagery to complement the SLAR data.

The process of transmitting the radar map to the central station is called cross linking. In this manner, within a few hours, a complete map of the ice environment could be built. During the day, additional maps of reduced size could be transmitted back to the central station to monitor, in near real time, the ice movements and assist in the planning process. This function would utilize the radar mapping component of the G-2 system.

4.4.8 Precise Positioning

Precise positioning refers to the ability to determine the ship's position with an accuracy of better than 10 metres or so. In many instances while navigating in blowing snow, near ice and snow covered low lying land features, the coast line becomes undistinguishable from the rest of the environment. This situation applies to both radar display and visual reconning. This may pose a problem during a port entry, or while in transit through a narrow passage where shoals are present. It is necessary, in these conditions, that the system be capable of supporting precise positioning functions whatever the source of the positioning data may be. This support will mostly be in the form of electronic chart overlay, annotation aids and relative position calculations. Until the full GPS network is deployed, few options exist to solve the problem of precise positioning. The G-2 system should be designed to allow the future integration of precise positioning information (whatever the source) using electronic chart data.

4.5 Additional Data Sources

In addition to airborne and marine radar image sources, the system will receive information from various other sources. These sources may provide image data or other forms of information that will be needed by the system. For the most part, image data will be treated as any other image information handled by the system. Satellite imagery will require additional or special processing which is described below. The remaining

data sources will be used for generic G2 tasks or to increase the usefulness of the system and its functionality.

4.5.1 Satellite Images

Satellite images will be received on board in two different formats and resolutions: APT format (Automatic Picture Transmission) and HRPT format (High Resolution Picture Transmission). The system will be capable of displaying and manipulating the satellite images with the same flexibility as the radar and SAR images.

In addition to image handling facilities, the system will provide a wide range of image enhancement techniques developed for remote sensing purposes. Such methods as false colouring, LUT (Look Up Tables), transfer curves, histogram equalisation, etc., will be provided to process the satellite images. In the case of the HRPT format, the transmitted data comprise five frames representing the five wavelengths of the AVHRR sensor (refer to Section 3.1). It is conceivable that the five frames may be combined to produce a high quality image of the area of interest. The system should be capable of handling the satellite images in monochrome or in colour, depending on which display monitor is used. Full annotation of the satellite images will be possible, including the overlay of geographic reference lines.

The user should be presented with a menu to select which images to receive and when to receive them. Because the storage capability of the system will be limited, some form of data management will have to be exercised. Either the images will be received on a voluntary basis, or the incoming data will be rotated through a limited number of files, the earliest images being entered in the system as the oldest ones are being discarded.

4.5.2 Sonar Images

Close range ice hazard detection has been the subject of significant research in recent years. From this research, the specifications for an ice strengthened front looking sonar have emerged. It is expected that this sonar will be constructed in the near future and field testing will be undertaken. The detection range of this sonar will be near 1 km with a azimuth beamwidth of approximately 15 degrees. The update rate of the images will be very low because of the speed of propagation of sound waves in water. Therefore, this source of imagery will not have an impact on the system performance and the images will be handled as all other images in the system.

4.5.3 Historical Database Management

Historical data are an important aspect of the G2 system, as it provides the user with a statistical tool to assist him in the prediction of transit performance and the evaluation of suitable routes. Historical data consists of accumulated ship's operational data correlated to environmental data such as ice type, thickness, etc. In addition to these data, representative SAR, radar and satellite imagery will be stored in memory for future reference. These data will be entered in a correlated data base and complemented by an expert system to access and analyze the information. As the ship proceeds through ice, all the data will be correlated and translated to quantifiable variables that can be handled by the system. Current data will be added to the data base according to preset rules and conventions. The expert system will then allow the user to make predictions based on accumulated data in similar operating conditions.

5. System Requirements

5.1 Architectures

5.1.1 Hardware Architecture

The hardware architecture will consist of 19" standard rack units. Experience has shown that industrial grade equipment was suitable to withstand the shipboard environment. Radars, communications equipment, and even standard commercial grade computer have been used successfully on board the vessel for several years. However, high end industrial grade equipment is recommended for the implementation of the G2 system. Shock mounts should be used throughout, and the power source should be conditioned. An uninterruptible power supply is highly recommended.

The computer system will be implemented using a standard architecture such as VME, MULTIBUS II, Q-Bus, STD-BUS, GESPACK, etc. The choice of the specific standard architecture will be made at the time of the implementation. The system will consist of a primary bus to which secondary or parallel buses will interface. The primary bus will constitute the main data exchange and connection unit. To the primary bus, will be connected a variety of modules that will perform interface, processing, display, data acquisition or storage functions.

Each module may consist of a single card compatible with the primary bus standard, or a unit consisting of a complete subsystem that will connect to the primary bus via an interface card compatible with the primary bus standard. The modules consisting of a subsystem can be implemented using any architecture suited to the task, as long as the interface remains compatible with the primary bus and that the subsystem meets the module specifications.

Many standard architectures specify an additional transfer bus or buses for high speed and simultaneous data transfer between modules. Maximum use should be made of these additional data exchange paths, to keep the primary bus data transfer and usage to the lowest possible level. The number of modules connected to the primary bus should be kept to a minimum, in an effort to allow for future expansion. Therefore, as many functions as possible should be implemented on each module connected to the primary bus.

5.1.2 Software Architecture

The choice of software for both the operating system and the main programming language is crucial to the performance of the system. The system performance is directly dependant on the quality and flexibility of the operating system. Conversely, the choice of the programming language has a direct impact on the ease and speed of development and to a lesser degree on the performance of the end product.

The operating system will be chosen for its flexibility and ability to allow direct interaction with the system hardware. Given that hardware components are usually addressed through software "drivers", the operating system definition and documentation will be sufficiently detailed to allow the development of such drivers in a straight forward manner. The chosen operating system will allow the system to respond to external events in near real time (real time operating system).

The software will be written in modular format, in a layered arrangement. The application will be built up of routines written to perform specific operations or resolve specific problems. Each layer will consist of a collection of routines that call upon routines of the previous levels for execution. In this manner, higher level layers will be called upon to perform increasingly complex and specific tasks. Lower level routines will be written in a generic way, in order to promote their use by higher level routines. The levels and the structure of the routines will be well defined so that third parties can

supply software for the system. Hardware dependency of software should be kept within the lower layers.

5.2 Display Requirements

The system displays will be used for three purposes:

1) Display high resolution grey scale images
2) Display high resolution colour images
3) Interact with the user through the use of menus and windows

The first application covers the display of radar images, satellite images, SAR images, and any other image that does not require the use of colour for adequate presentation. The second application covers the display of colour images (electronic camera), colour enhanced monochrome images, and colour annotation of displayed images. The third application covers the use of windows and menus implemented in colour or grey levels.

Two displays will be necessary in order to view the radar image and the SAR image simultaneously. Monochrome images will by far be the most common in the system and will require the highest resolution display and the largest viewing area. The monochrome display will be provided with real time zoom and pan capability. A colour display is not a necessity but will enhance the quality of the user interface, and will allow the display of various image enhancements that monochrome displays cannot handle. Most of the navigating functions will be performed on the monochrome display, while commands and system control will mostly be performed on the colour display. The monochrome display will have a minimum of 4 megapixels of display area at a minimum of 16 grey level capability (equivalent to the SAR imagery dynamic range). The colour display will have a minimum of 1 megapixel display area at a minimum of 256 simultaneous colours. In both cases, the display size should be at least 20" diagonally.

In addition to the two main display, a data entry terminal will be required for text editing, data entry, and user interface purposes. The data entry terminal will be smaller than the two main displays and will only have alphanumeric capability.

Additional displays, located in remote areas of the bridge, will be included in the system architecture. The number, size and capability of the remote displays is to be determined. The remote displays will be used for such applications as displaying annotated radar images at the front of the wheelhouse for the navigating personnel. In addition, the remote terminals will be supplemented with limited user interface to allow a menu selection and other functions without having to go back to the ice navigation console.

Display requirements also cover the need for hard copy image production. The hard copy image printing device should be capable of producing strips of imagery of at least 2,048 pixels across and at least 12,288 pixels long (6 times the width). The printer will be capable of reproducing 256 grey levels at the full resolution of the printer. The printer will interface to the G2 system through a digital interface capable of handling at least 75% of the data transmission rate of the downlink. The printer should be capable of printing on paper or transparent media. The printing device should use a printing process that requires no intervention from the user other than the loading of the media (i.e., dry silver process). The print density should be at least 10 pixels/mm and the aspect ratio of the image should be digital in nature, i.e., the pixel and line spacing should be fixed and correspond to the maximum resolution of the machine. All the machine controls should be accessible through commands issued on the system interface. Full control of the length or width of image to be printed should be available. In addition to the hard copy image printer, the system should include a text printer capable of producing medium quality graphics.

In addition to the above mentioned displays, the system will incorporate any dedicated display that may be useful to inform or warn the operator of the system status

or actions. Such devices as a mimic panels fitted with LEDs (Light Emitting Diodes) or other indicators can be considered.

5.3 Storage Requirements

The system storage requirements can be separated in three groups:

a) Live memory (RAM or ROM)

The live memory consists of any memory that is directly accessible by the main system or a particular system module without the need for an interface. Live memory will be used for temporary storage of data to be processed, loading programs to be executed, and the storage of any information the associated processor may need direct access to.

b) Mass storage (winchester or optical)

Mass storage refers to large quantity storage devices that must be accessed through an interface such as a SCSI interface. The storage media cannot be removed or replaced and the storage it provides is considered a fixed asset of the system. Mass storage will be used to retain software, image data, data base information, or any data that must be available to the system without any user intervention but that does not need to reside in the system's memory. This type of storage is considered permanent and remains after power shut down.

c) Archive storage (optical storage or magnetic tape)

This type of storage is dedicated to the archiving and retrieval of data that are no longer required in the present time, but may be required in the future. Such devices as tape units, optical disks are typical of the technology used to implement archive storage. These devices interface to the system much in the same manner as the mass storage devices, however they must rely on the

operator to insert the correct media in the device. These devices are usually slower than mass storage devices.

For each of these items, the amount of storage can be distributed within the system or throughout a number of external peripherals. Regardless of the location of the storage, the amount of the required storage will not change and, therefore, calculation can be undertaken without the need to know the specifics of the hardware. Such calculations have been undertaken in Section 6.1 and the results shown here:

Live memory:

Main memory = 20 megabytes
Image display = 25 megabytes
Image processing = 15 megabytes
Total = **60 megabytes** of live memory

Mass storage:

Shipboard radar = 600 megabytes
Satellite imagery = 600 megabytes
SAR/SLAR imagery = 1.5 gigabytes
Video images/others = 100 megabytes
Software/database storage = 125 megabytes
Total = **3 gigabytes** of mass storage

Archive storage:

No calculations are necessary for this group. The required storage capacity corresponds roughly to the mass storage capacity. The selected storage device will be the one with the highest storage density available. It is unlikely that data from the mass storage media will be archived en block, therefore, an archive storage media of equal capacity to the mass storage is not necessary. Rather, the data will be archived in related

blocks of information such as all the data files associated with a SAR mission for example. An archive storage media size of 1 gigabytes would be quite adequate.

5.4 Speed Requirements

The system speed requirements are primarily concerned with the data exchange rate and the necessity for the system to handle the full data bandwidth of the data sources, either simultaneously or in near real time (with a few seconds delay). Several sections of the system will have different speed ratings depending on the task to perform and the amount of data to be handled. The analysis is best performed by looking at each data source independently, and comparing it with the expected system bandwidth. This analysis is not concerned with the data handling rate of each module, but rather, with the limitations imposed by the data exchange path that links all modules together in the system. Therefore, the common data exchange path is the limiting factor. Allowances will be made for future expansion. All calculations associated with this section can be found in Section 6.2.

5.4.1 Radar Data

The radar data rate will depend on both the ship's speed and the operating mode. Two main operating modes will be implemented:

a) Mapping mode,

Whereby the radar image of the static ice environment is updated at the rate of advance of the vessel. If the vessel is stationary, no update is necessary. The faster the speed of advance, the more data has to be transferred to the display module of the system.

b) Full frame mode,

This mode corresponds to semi open water navigation whereby the image is updated as often as the antenna sweeps the environment. In addition the HH and HV channels are required to perform the required hazardous ice detection techniques.

Any combination of the two above modes are possible, with associated data transfer rates. It is intended that the data acquisition module will perform processing including scan conversion. The result will be transmitted in the form of a cartesian image to the system processing and display modules.

For the above two modes, the data rates have been calculated at:
Mapping mode = 20 kilobytes/second
Full frame mode = 4 megabytes/second

5.4.2 SAR/SLAR Data:

SAR and SLAR images share the same format, same transmission frequency, and same hardware. Since the SLAR images do not contain as much information as the SAR images, the SLAR transmissions must be padded for transmission uniformity with the SAR images. Therefore, the SAR image transmissions are the most data intensive and calculations of data rates were based on SAR image reception. The full SAR image transmission rate on the system bus will be 87.5 kilobytes/second.

5.4.3 Satellite Data

The NOAA satellites transmit both APT and HRPT images. Only two APT image bands are transmitted during a satellite pass, while 5 image bands are transmitted in HRPT format. Conversely, the METEOR satellites transmit one image band on APT format thus offering higher resolution images on APT than the NOAA satellites. The

resolution available on HRPT format is up to four times better than on APT format. It is unlikely that both image formats will be received simultaneously by the system, since the APT and HRPT formats are derived from the same sources.

The calculated image transmission rate on the system data bus are as follows:

HRPT = 332.5 kilobytes/second
APT = 4.16 kilobytes/second

5.4.4 Other sources

None of the remaining sources of data (SONAR, ship performance, etc.) will require the data transfer rates that the above mentioned sources generate. In addition, none of the remaining sources will have the priority that the above sources have. To allow for system management, operating system overhead, usual disk and memory transfer, a maximum of 5 megabytes/second data transfer rate can be allocated for the remaining combined sources, assuming that all sources require simultaneous transfer. At times when the data bus is not so occupied, this transfer rate could be increased to any desired level within the capabilities of the system.

5.4.5 Total Bandwidth

From the above calculations, a maximum data transfer rate for the system can be calculated and totalled:

Radar	4	megabytes/second
SAR	0.0875	megabytes/second
Satellite	0.3325	megabytes/second
System	5.0	megabytes/second
Total	9.42	megabytes/second

Considering that most modern high efficiency buses are capable of sustaining 40 megabytes/second data transfer rate, the system in full activity would not use more than 25% of the available bandwidth. This 75% margin allows for ample expansion and no bottle necks in execution speed.

5.5 Other Requirements

5.5.1 Physical Requirements

The G2 system will be installed in what can be considered an industrial environment. Industrial grade equipment can be found throughout the M.V. Arctic. These equipments are located anywhere from the lower levels of the engine room, to the confines of consoles on the navigation bridge. The environments range from very harsh to totally controlled and protected. In all the years the M.V. Arctic has operated, none of the equipment has failed, or has been proven to have failed, because of the shipboard environment. On the bridge, where the G2 system is most likely to be installed, equipment is well protected and not subjected to extreme variations of temperature and airborne contaminants. Radar systems, communications equipment, navigational aids, are all constructed to industrial standards without detriment to their reliability. Personal computers are used at many locations on the M.V. Arctic without any protection other than good padding under the unit. These computers have operated for years without any failures other than what can be expected for this category of equipment. It is therefore recommended that the G2 system be constructed to industrial standards and no more.

The system should be built to standard 19 inch rack dimensions. The size and physical arrangement of the system should promote easy maintenance, protection from the environment and adequate cooling. Connectors, switches or other set up and configuration devices should be clearly visible and identified. Adequate shock mounting should be provided for all delicate components such as hard disk or monitors. The system should be connected to a surge protection circuit and a power conditioner/backup unit.

Any custom hardware for the system should be constructed to high industrial standards, implemented in printed circuit board technology. No wire wrap wiring techniques should be used for any of the final components of the G-2 system.

5.5.2 Expansion Requirements

The chosen hardware architecture should allow at least 50% expansion over the full system configuration. For this purpose, it is suggested that secondary buses be used and that the system be constructed with as many subsystems as required. Subsystems should be built and selected to minimize data transfer on the main system data bus. Most modern buses offer several solutions to the expansion problem.

5.5.3 Reliability/Compatibility Requirements

The reliability issue will arise in any system development, but more so in complex systems. Perhaps the best defense against failure, further to judicious choice of equipment, is building redundancy into the system. This is the approach that would be preferred in the G2 system. Redundancy can be built into the system functionally and physically. Functional redundancy is accomplished by having one module take over the functions of another. Physical redundancy is the direct replacement of a faulty module by a functional one. Both kinds of redundancies should be implemented in the system and the decision to implement one or the other should be a matter of cost/benefit.

The chosen architecture for the hardware base should have specifications that leave no room for ambiguity. All parameters of the system should be specified in such a way that components for the architecture can be purchased from any vendor, with minimal risks of incompatibility. The adherence to the architecture standard should be regulated by an organisation whose sole function is the promotion of the standard and the monitoring of its application.

6. Calculations

The calculations undertaken in this section are only intended to be used as a guide in order to evaluate the system's requirements. The final product may deviate from these estimates as the applications are brought on line one by one and the requirements are refined.

6.1 Storage calculations

6.1.1 Live Memory:

Main Memory:

The main system memory should be capable of holding multiple concurrent time sharing applications (software and data), it should hold the active components of the operating system, it should be large enough to hold a large quantity of image data to perform buffering operation or background image analysis functions. The main memory should have a word width the same size as the main data transfer bus, should support maximum bus operating speeds and be directly accessible in contiguous memory locations. The following requirements can be estimated:

- Image data = 10 megabytes
- Software = 5 megabytes
- Special applications = 5 megabytes

Total = 20 megabytes

This estimate is subject to revision and will again depend on the exact system configuration and operational architecture.

Graphics Display/Processing Memory:

The graphics display memory will be specified to accommodate the most demanding display requirement; SAR image display and tactical navigation.

One major improvement promoted in the G2 system is the ability to perform real time zoom and pan of the displayed imagery. Such a display performance is only possible if all the imagery to be displayed is present in the system's memory. Any request to display an image portion that would not reside in memory would require access to the mass storage devices. Data rates associated with mass storage devices are too slow to permit real time zoom and pan operations. Therefore, the range over which real time zoom and pan operation is required, determines the size of the required display memory.

Experience has shown that approximately three to five times the shipboard radar area (three times sideways and five times forward) must be examined on the SAR imagery in order to achieve good predictive navigation performance in ice covered waters. This "working area" of the SAR imagery is only valid once the strategic planning has been made and a general route is available. Given a radar range of 6 nautical miles, the total radar area is 12 x 12 nautical miles. The corresponding SAR working area is then 60 nautical miles x 36 nautical miles. At a resolution of 15 metres/pixel and 4 bits/pixel, the required memory area is:

60 x 1,853/15 x 36 x 1,853/15 x .5 = 16.5 megabytes.

In order to provide the user with a comfortable margin and ample working space, this figure is increased by 50% to: 16.5 megabytes x 1.5 = 25 megabytes

In addition to the above display memory, some space must be provided for image processing that is independent of the display memory but has access to the high speed private graphics bus. This image processing memory must be able to contain two images

of a minimum size equivalent to the display area at the full dynamic resolution of the most accurate information source. The purpose of this memory is to allow full accuracy image processing on the incoming data in order to yield processed images at the reduced accuracy and resolution for display. The radar and satellite imagery are 10 bits in dynamic range and, therefore, the processing memory should allow to keep this data size. The allocation of 12 bits (1.5 bytes) per pixel would seem adequate for image processing and would allow for future increases in dynamic range. Using the largest display area as a guide, 2,048 x 2,048 for the monochrome display, the processing memory can be calculated:

2,048 x 2,048 x 1.5 x 2 = 12.6 Mbytes of memory that can be rounded up to 15 Mbytes.

In addition to the above memory requirements, each additional display must be provided with the required amount of memory. The memory requirements are dependent on pixel word size, the presence or absence of colour, and the requirement for real time zoom and pan or not.

To summarize this section, the following figures are recommended:

Main memory	=	20 megabytes
Image display	=	25 megabytes
Image processing	=	15 megabytes

6.1.2 Mass Storage

The mass storage requirements are easier to define since the storage requirements are associated with the quantity of data only and not a combination of both processing and quantity. The data to be stored is divided in 5 groups:

- shipboard radar data
- satellite HRPT and APT images
- SAR/SLAR imagery
- video images and other sources
- software, databases etc.

6.1.2.1 Shipboard radar

The shipboard radar data will be processed in the radar data acquisition module to produce data that can be handled by the graphics processing/ display subsystem. Two sources of radar data are available and the radar data system should be able to handle both data flows simultaneously.

The radar data will first be processed to increase the far range resolution and normalize the signal. The data will then be scan converted for further processing. Subsequent processing will contribute to the construction of a progressively larger map of the incoming radar data. Successive sections of the radar map will be transferred to the graphics display subsystem where it will be stored. It is this radar map that will require most of the data storage.

The storage evaluation will be based on the storage of radar map at the expected most common resolution; 8 bits/pixel and 7.5 metres/pixel resolution. Even though the system should be capable of resolving features as small as 3.75 metres in range and 10 bits/pixel, this high resolution will only be used in the radar image acquisition module for

processing purposes. It is not believed at this time that meaningful information of the ice surface will be received beyond 10 nautical miles in range. Therefore, the potential exists for a radar map 20 nautical miles wide. The radar map may well extend to 200 nautical miles/day and even though only 75 nautical miles would be needed at any time, the full map should be available from the mass storage if required. Calculations for the radar map are as follows:

200 nautical miles
1 byte/pixel
20 nautical miles map width
7.5 metres/pixel resolution
1,853.184 metres/nautical mile

20 x 1,853.184/7.5 x 200 x 1,853.184/7.5 x 1 = 244 megabytes

In order to allow expansion, this figure will be rounded off to 300 megabytes. In addition, the two channels of radar data must be stored separately thus doubling the storage requirement to 600 megabytes. This sets an upper limit to the required mass storage for radar data.

6.1.2.2 Satellite imagery

The calculations for satellite imagery will be based on the largest source of satellite data; the High Resolution Picture Transmission (HRPT) images. The HRPT images are 2,048 pixels wide and as long as 5,400 lines (15 minutes of transmission in the best conditions). Images from five channels are transmitted simultaneously at the above resolution. A total of 3 to 4 transmissions could be received every day from which the user would select what is to be archived, freeing space for subsequent data. Sufficient storage space should be provided to accommodate two days of incoming data. The full resolution data is transmitted in a 10 bit word format. For storage and display purposes,

the dynamic range can be reduced to an 8 bit word without significant loss of visual clarity. The calculations are as follows:

2,048 pixels/line
5,400 lines/image
5 images/transmission
4 transmissions/day
2 days of storage
1 byte/pixel

2,048 x 5,400 x 5 x 4 x 2 x 1 = 442 megabytes of data

This figure can be rounded up to 450 megabytes.

In addition to the HRPT image transmissions, the satellites transmit images in the APT format which is 1,800 pixels wide and up to 1,800 lines long. For the same storage requirements as above but twice the reception frequency, the calculations are as follows:

1,800 pixels/line
1,800 lines/image
8 transmissions/day
2 days of storage
1 byte/pixel

1,800 x 1,800 x 8 x 2 x 1 = 52 megabytes of data

Allowing for twice this amount of storage because of possible AES image transmissions plus soviet satellite transmissions, the storage requirement is set at 100 megabytes.

Therefore the total satellite transmissions will be the total of 450 and 100 megabytes of data (550 megabytes). For simplicity and security this figure is rounded up to 600 megabytes. Future satellites will have an increased in resolution by a factor of 1.375 (Fisher, J., 1989). If this figure is applied to both axis of the imagery, we obtain a data increase factor of 1.9 or almost two. It would be unreasonable to expect a proportional increase in storage requirements, instead, the user will be expected to be more selective about the data that will be stored. For example, five HRPT frames are received during each transmission. Out of the five received images, one or two can be selected and the rest deleted or archived on tape. Out of the four possible transmissions per/day (eight if the two days storage requirements are condensed in one day) one or two can be selected as the most useful ones. In addition, the new system will be able to predict exactly the time and quantity of data to be received. The need to take into account satellite orbital and transmission characteristics is made necessary by the need for a directional satellite dish to receive the HRPT images. The fact that orbital and transmission characteristics are known, will make data management more predictable and consistent.

6.1.2.3 SAR/SLAR imagery

The SAR imagery is the most data intensive of the SAR and SLAR imagery. The images consist of lines of imagery that are variable in length but have a fixed pixel width of 4,096 units. Two resolutions are available for the SAR imagery, 15 metres/pixel or 25 metres/pixel. The pixels are four bits wide and thus two pixels can be stored per byte. Images from both sides of the aircraft can be transmitted simultaneously; however, this only has an impact on the transmission data rate and not on the total storage requirements. Typically, 1,200 nautical miles will be flown during one mission and the system should accommodate the full data storage requirements associated with this data.

Calculations are as follows:

4,096 pixels width
15 metres/pixel (maximum resolution)
1,853.184 metres/nautical mile
1,200 nautical miles/mission
.5 bytes/pixel

4,096 x .5 x 1,200 x 1,853.184/15 = 305 megabytes/mission

To this figure, a security factor of 60% percent is added for unexpected events and to cover possible extra image manipulations (such as having an extra copy of the total mission at half resolution directly available from disk) and other requirements, giving an upper limit of roughly 500 megabytes. At least three missions should be accommodated at the same time, taking the upper limit to 1.5 gigabytes. The SLAR imagery requirements are much less stringent than the SAR imagery and is similarly formated, therefore, the SLAR imagery requirements are well covered by the SAR requirements.

6.1.2.4 Video images/other sources

Video images have been added to the system as an extra utility since the system has the capability of dealing and processing this type of information. Video images will be taken with an electronic camera that will have a maximum resolution of 2,048 x 2,048 pixels, at one byte/pixel. Therefore, the storage requirements for an image is roughly 4 megabytes. Very few images will be required for display at any one time. Chances are that the images will be stored on disk only long enough to be printed or archived. A arbitrary total of 10 images should be adequate for most purposes, setting the upper limit to 40 megabytes of image storage. Any other image source will be limited to the one viewing screen size, which will be approximately 4 megabytes maximum. Setting the maximum number of images from these other sources to 10, we have the same storage

requirement for a total of 80 megabytes. The resulting 80 megabytes can be rounded off to 100 megabytes, which should cover most requirements in that group.

6.1.2.5 Software/database storage

Most software and data base requirements can be handled by the same standard disk size than commercial systems (such as the SUN work station) use, which is usually in the 125 megabytes size. This size of data storage should handle the operating system, a series of application programs, general utility software and a good deal of database data. Additional storage requirements can easily be accommodated by installing an extra hard drive in the future.

6.1.2.6 Summary

To summarise the various requirements, the following recommendations can be made:

- Image storage

radar	600 megabytes
satellite	600 megabytes
SAR/SLAR	1.5 gigabytes
video/others	100 megabytes
Total	2.8 gigabytes

- Software/data 125 megabytes

It is recommended that separate drives should be supplied for each set of imagery i.e., radar, satellite, SAR. This will help provide some degree of redundancy in case of

failure of one drive. This approach may also provide faster access to the data by allowing parallel access to the information.

6.2 Speed calculations

6.2.1 Radar Data:

The radar data will be transmitted to the main system from the radar data acquisition module. Two modes will be implemented on the system; the mapping mode and the full frame mode. Referring to Section 5.4 for additional information, the following calculations apply for each mode:

Mapping mode:

In the mapping mode, the forward looking portion only (forward 180°) of the radar environment will be transmitted to the main system. The image will have a maximum range of 6 nautical miles and a resolution of 8 bits/pixel and 7.5 metres/pixel.

6 nautical miles range
7.5 metres/pixel
1,853 metres/nautical mile
8 bits/pixel
2 radar channels (HH and HV)
.1 nautical mile update rate
12 Knots maximum ship's speed

range = 6 x 1,853/15 = 742 pixels
area/scan = 742 x 742 = .55 megapixels
forward area = .55/2 = .275 megapixels
update time = 60 minutes x update distance/ship's speed
= 60 x .1/12 = .5 minutes

data quantity = .275 megapixels x 1 byte/pixel x 2 channels
= .55 megabytes
data rate = data quantity/update time
= .55/30 = 18 kilobytes/second

This figure can be rounded to 20 kilobytes/second

Full frame mode:

In this mode, the full frame will be transmitted as often as the antenna sweeps the environment. The antenna rotation rate and PRF must be such that in a complete revolution all pixel locations within the matrix that corresponds to the chosen range will be addressed. For the full frame mode, only medium resolution is required, the refresh rate and coverage being more important than high picture quality. In these conditions, the following maximum settings apply:

6 nautical miles range
20 Mhz sampling frequency
3.2 Khz pulse repetition frequency

For the above settings, the antenna rotation rate can be calculated at 4.12 seconds/revolution. A complete frame will be transmitted to the G2 system every 4.5 seconds, rounding the figure. With an image matrix corresponding to 12 x 12 nautical miles (6 nautical miles range), the following calculations apply:

7.5 metres/sample
12 nautical miles => 2,965 samples (pixels)
total image size = 2,965 x 2,965 = 8.8 megapixels
given a word size of 8 bits, the total image size is 8.8 megabytes
effective data rate = 8.8/4.5 seconds = 1.95 megabytes/second

This figure must be doubled for the two HH and HV channels and rounded to 4 megabytes/second

6.2.2 SAR/SLAR Data:

Both images share the same format and the same transmission frequency and hardware. Therefore both images will be described here. The SAR data is transmitted at a rate of 700 kilobits/second. This rate corresponds to the full annotated image frame, plus the SDLC protocol overhead. The actual data transfer rate will thus be somewhat less than 700 kbits/s. This data transfer rate is the same for single side or double side SAR, as well as high or low resolution SAR. Once the image has been received and deformatted, the data will be sent on the bus at 700 kbits/8 bits = 87.5 kilobytes/second, a data rate that is much lower than the radar data.

6.2.3 Satellite Data:

The satellite data transfer rate depends on the format of the transmitted images. Calculations will be made for the HRPT and APT image formats. It is unlikely that both APT and HRPT images will be received simultaneously since the APT is a repeat of the HRPT format. Most of the images handled by the system will be handled in 8 bits/pixel. The HRPT images are transmitted at 10 bits/pixel and therefore will be reduced to 8 bits before being transferred on the data bus.

The HRPT format is transmitted at a rate of 66,540 words/second with very little overhead in terms of header etc. The data transmission rate over the data bus will therefore be essentially 66.5 kbytes/second. Future versions of the weather satellites will transmit data at 5 times the present rate. This would take the data transfer rate to 332.5 Kbytes/second.

The APT format transmission rate is much lower and is derived from the digital origin of the transmitted analog image. The images are constructed of lines containing 2,080 words of data fed to an D/A converter. The line rate is 2 lines/second and therefore the data rate is equivalent to 2 x 2,080 = 4.16 kbytes/second.

7. First Generation Ice Navigation System

The contrast that exists between the existing ice navigation system and the proposed second generation system is described in this section.

7.1 System Hardware

The first generation system consists of a navigation console, shown in Figure 7.1, fitted with or connected to the following equipment:

1) STAR-VUE II, SAR reception and display system
   - Digital, PDP-11/83 computer frame
   - 600 megabytes disk storage
   - Exabyte, 2 gigabytes tape archive unit
   - Hitachi High resolution (1,280 x 1,024 pixels) colour display
   - IDS, High resolution continuous tone image printer
   - Aydin Vector, model 2713 SAR downlink receiver

2) MARINE-VUE, marine radar raster display system
   - MARINE-VUE control panel
   - Video combiner unit
   - Scan converter unit
   - Medium resolution (512 x 512 pixels) colour monitor

3) VIEWFAX, weather satellite receiving and display station
   - DEC 11/23 computer
   - 128 kilobytes live memory
   - 80 megabytes winchester hard disk unit
   - 1 megabytes video memory
   - AED 512 video interface unit

- Medium resolution (512 x 512 pixels) colour monitor
- VHF receiver + power supply
- Facsimile to digital interface unit

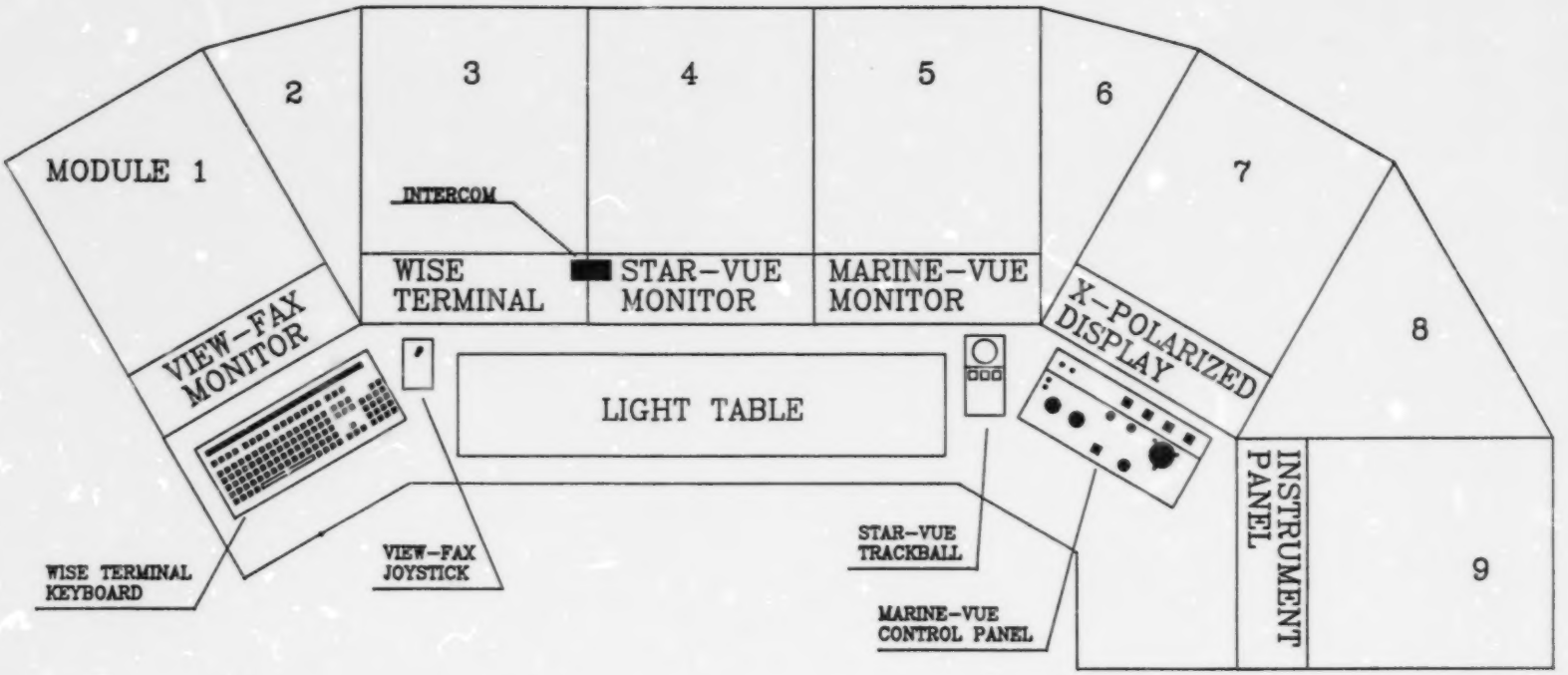
4) Hard copy image printer
5) Computer terminal
6) VHF aviation frequency two way radio
7) Satellite navigator
8) Heading indicator
9) Radar display selector
10) Light table

7.2 System functionality

The system functionality is best described by taking each component separately:

1) STAR-VUE II:

The STAR-VUE II system is capable of receiving SAR and SLAR imagery. The system is capable of storing, archiving, displaying and printing the received imagery. The system is capable of storing the equivalent of only one mission on hard disk media. The display system includes capabilities to perform route planning, zoom, pan, annotation, rotation, colour look up table enhancement, and other lesser functions. The menu driven user interface is both slow and not comprehensive.



SINSS ICE NAVIGATION CONSOLE
(PLAN VIEW)

Figure 7.1 SINSS console

Functions such as calling a new part of an image may take as much as 4 minutes to perform, contrary to the requirement of Section 4.1.1.

Image reception facilities are difficult to operate and image reception is only possible if all mission particulars have been entered in the system and the set up completed. These shortcomings are contrary to the requirements of Section 4.2.1. Received images cannot be manipulated or printed until well after the completion of the total mission.

The computer system is slow, has very limited expansion capability and is not well supported by third party manufacturers. The operating system is not well suited to the kind of work demanded of the machine. Expansion and architecture requirements are covered in Section 5.1.

2) MARINE-VUE:

The radar display system, however complex, fails to meet the requirements outlined in Section 5.3. The display area is limited to a 512 x 512 pixels area. The full resolution of the radar data cannot be achieved when the range is increased beyond 2 nautical miles, since the machine adjusts the sampling frequency to match the chosen range to the number of display pixels. No mapping is performed. No radar control is possible.

3) VIEWFAX:

The VIEWFAX system is the most adequate of all the components of the present system. Despite certain deficiencies such as some image distortion of the Soviet images, APT image reception only and a restricted selection of enhancement options, the system is easy to use, reliable, and performs the functions it is intended to perform. Most of the functions performed by the system will be repeated in the G2 system, with the addition of certain features as described in Section 4.5.1.

4) Hard copy image printer

The hard copy image printer is subject to numerous sources of dimension inaccuracy. Numerous adjustments to speed, contrast, heater temperature and other parameters have to be made in order to get a good picture quality. In addition, the printer cannot accommodate transparent media. The produced image quality has been found in all cases to be less than satisfactory. The requirements corresponding to the image printer can be found in Section 5.2.

The remainder of the components will be included in the G2 system implementation as is, being connected to it or fitted near it for convenient use. The present system configuration and architecture cannot support information exchange or resource sharing among applications. The simple implementation of certain facilities on the MARINE-VUE display (range and bearing cursor, range rings, STC, gain and offset controls, north up display) cost upwards of $500,000 can dollars and required to build two custom units. The same implementation in the proposed G2 environment would have been a question of hours only. The computer chassis of the present system could not accommodate more cards to perform more functions, even if these cards existed. Most functions proposed in Section 4.4 could not be implemented in the confines of the present architecture, at least not to the required level of performance.

8. Second Generation Ice Navigation System Feasibility

In order to prove that most if not all the proposed G2 components and techniques were realisable, a limited market survey was made to find components that could potentially meet the G2 system requirements. In this study, key components or requirements were chosen such as display size or real time zoom and pan capability. For these items, a solution using off the shelf equipment was specifically sought. The items for which components were found are the following:

1) System hardware base
2) Computer and processing modules
3) Graphics interface subsystems
4) Analog and digital interface cards
5) Human interface devices
6) Image printer
7) High resolution monitors
8) Satellite receiving platform
9) Mass storage devices
10) Radar signal digitizing module

These items are developed further in the following sections. In addition, an example of a possible implementation is presented in Appendix I. The details of the presented implementation are not covered. Rather, a possible architecture is given and the various modules briefly described.

8.1 System Hardware Base

A variety of options exist when the time comes to chose the hardware base or bases for the system. The final choice will depend on the market support, the availability of components, the variety of components, the ease with which the chosen base can be

interfaced to other standards, the software support available and also the projected useful life of the chosen hardware base. This study will be limited to the presentation of the most commonly available options for the core system. According to specifications given in Section 5.1, any number of hardware standards can be used around the core system. To cover this, some 8 bit buses have been presented as well.

8.1.1 VME bus

The VME bus is strongly supported by over 250 manufacturers, employs an internationally accepted physical format, supports high speed data transfer in the order of 40 megabytes/second and is readily available worldwide. The bus is asynchronous in nature, contains a 32 bit data bus as well as a 32 address bus in addition to the required bus arbitration and control lines. The bus hardware and electrical specifications are well defined and are presented as IEEE standard 1014-1987. The variety of modules available for the VME bus range from the simple computer card and accessories, to highly sophisticated three card set image processors. In addition to the main bus specifications, several additional buses have been defined to implement high speed concurrent data transfer in the VME architecture. These additional buses are VXI and VSB.

8.1.2 MULTIBUS II

The MULTIBUS II architecture is similar to the VME bus standard in terms of system performance and dimensions. The bus is synchronous in nature, has a similar 40 megabytes transfer rate; however, the bus does not have separate address and data lines. This means that the bus has been designed for burst mode data transfer mostly. The card size is slightly longer than the VME standard but is the same width. In addition, both VME and MULTIBUS II utilise the same card connectors. The MULTIBUS II specifications are given in IEEE standard 1296-1987. The MULTIBUS II architecture is not as well supported in the industry (100 manufacturers versus 250 for VME), mainly

because of its relative youth compared to the VME standard which as been in use since the mid seventies.

8.1.3 STD bus

Introduced in the early 1970's, the STD bus is still an option of choice. Well established in the industry, the 8 bit bus offers a wide range of application boards that cover any small system requirement. The STD specifications are given in IEEE standard 961-1987. STD bus components are available worldwide, but more so in the U.S. where the bus widely used. The STD bus could be used to implement such secondary modules as a human interface or a radar system control unit.

8.1.4 G-64/G-96 bus

The G-64/G-96 bus is an 8/16 bit bus built on a standard eurocard format using a single DIN connector similar to that in use in the VME and MULTIBUS II standards. Originally developed by Gespac, the bus is in wide use in Europe and has steadily been gaining acceptance on the American continent. The G bus is strongly supported by a growing number of manufacturers. Components are available world wide. The G bus would be used in the same kind of application than the STD bus but offers more flexibility and performance.

8.2 Computer and Processing Modules

In the implementation of the G2 system, will require general processor boards and specialised processor modules. A number of single board computers (SBC) are available to perform general purpose functions. SBCs range from the low performance low cost units, to the high end RISC architecture high clock rate computer boards. Two examples of general processor modules are presented in Appendix J:

1) A selection of VME bus single board computers and processor modules from Motorola.
2) A selection of MULTIBUS II single board computers and processor modules from various manufacturers.

In addition to SBCs, special applications such as image enhancement and feature extraction will require special processors that can perform mathematical operations in a parallel architecture and a multiprocessor approach. Two examples of such modules are given in Appendix J:

1) A single board VME image processor module from Interactive Circuits and Systems Ltd.
2) A VME board set manufactured by Data Cube inc., for real time processing of images.

8.3 Graphics Interface Subsystems

The implementation of real time zoom and pan (Section 4.1.1) will require high performance graphics interface cards connected to high speed data transfer buses and memory cards of large size. An evaluation of the amount of live memory needed for the graphics subsystem is made in Section 5.3. A number of companies manufacture products to handle this application. Two products are presented in Appendix J, they are:

1) Matrox VG-1281 high resolution graphics processor, suited for 1,024 x 1,024 pixel colour graphics application. This processor offers real time zoom and pan capability out of a 4 megapixel area.

2) Datacube MaxVideo graphics systems, suited for large area viewing up to 1,300 x 1,024 pixels out of a virtually unlimited viewing area. This processor is supported by a proprietary bus, additional to the VME bus, for which specifications have recently

been made public domain. Processors for a larger 2,000 x 2,000 pixels display are currently under development.

8.4 Analog and digital interface cards

The acquisition of auxiliary data such as the radar antenna azimuth, the wind speed, the ship's speed, and the ship's heading will require analog and digital data converters and acquisition boards. In any of the architectures mentioned in Section 8.1 data acquisition and conversion are very well supported and a wide selection of boards are available. A few examples are given in Appendix J:

1) A selection of VME boards from VMIC (VME Microsystems International Corporation).
2) A selection of MULTIBUS II boards from various suppliers.
3) A selection of STD boards from WinSystems.
4) A selection of G-64/96 bus boards from Gespac.

8.5 Human interface devices

Control of the system's functions, selection of menu items, selection of image locations and pointing to image features will require entry devices. A large variety of entry devices exist: track balls, mouses, light pens, touch screens and joy sticks. A selection of certain of these devices are presented in Appendix J:

1) A touch screen manufactured by Trillium Industries Inc.
2) Three models of track balls manufactured by Measurement Systems Inc.
3) A selection of joysticks and control grips manufactured by Measurement Systems, Inc.

8.6 Image printers

The characteristics of the image printer are outlined in Section 5.2. A number of devices will meet the requirements in part, but none of the ones evaluated will meet the complete requirements. The printer that most closely matches the specifications outlined in Section 5.2 is presented in Appendix J. The device is manufactured by Lasertechnics Inc. The company is presently undertaking the redesign of certain components of their machine. The modifications will bring their machine much closer to the G2 requirements.

8.7 High resolution monitors

The amount of imagery that can be viewed at any one time is dependent on the size and resolution of display monitors. For a number of years, the standard display size has been 1,280 x 1,024 pixels. Because of the trend in the industry towards higher resolution and higher quality image display systems, monochrome monitors with a display area of 4 megapixels (2,048 x 2.048) have become available. Such a monitor, manufactured by DisplayTEK, is presented in Appendix J.

8.8 Satellite receiving platform

The reception of satellite data on board a ship requires the use of stabilized dishes for C and S band transmissions. In addition, a receiver having the right characteristics must be used. Most of the commercial equipment in use today is oriented towards land stations. Very few systems have been built for a marine application. The implementation of a system on board a ship will require the adaptation and modification of existing technology. Certain of the components that could be used for this application are presented in Appendix J:

1) Two dual axis antennas manufactured by ELECTRO-MAGNETIC PROCESSES INC.

2) Two antenna control units manufactured by ELECTRO-MAGNETIC PROCESSES INC.
3) One HRPT format, NOAA satellite data receiver manufactured by Aydin Monitor Systems

8.9 Mass storage devices

Section 5.3 defines the total storage requirements, in main memory, mass storage, and archive storage. An example of three devices that could be used in the G2 system is presented in Appendix J:

1) System memory boards for the VME architecture, manufactured by Motorola. Capacity ranges from 1 to 16 megabytes of data.
2) A high speed hard disk drive system with controller for the VME system. The capacity reaches 2.8 gigabytes and the data transfer speed can be up to 12 megabytes/second. The unit is manufactured by IBIS Systems Inc.
3) An archive tape backup unit based on 8mm cartridge video tapes. Manufactured by EXABYTE Corporation, the unit can store up to 2 gigabytes of data.

8.10 Radar signal digitizing module

A number of companies have developed scan converters or data acquisition modules that will digitize data at 20 Mhz and 8 bit data words. Canadian Marconi, Offshore Systems Ltd. and Crossbow Ltd have developed full scan converters (digitization and scan conversion), while Nordco Ltd. developed only an acquisition module. The Nordco Ltd. module can digitize radar data at a rate of 40 Mhz, while the scan converters developed by the above companies can only digitize at up to 30 Mhz or so. In addition to these modules, components capable of digitizing data in a format compatible with the requirements of Section 4.3.2, are commercially available. One of these modules is presented in Appendix J.

9. Conclusion

The majority of the G-2 functions and requirements are easily within reach of today's technology, as demonstrated in Section 8 of this report. The uniqueness of the G-2 system resides in the way the various techniques and technologies available today will be assembled into a high performance, open architecture and multifunctional system. This system will allow the implementation of all the techniques described in this document, and will provide a platform for the future development of related technologies.

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Appendix A

Example of Long Range Strategic Planning Analysis

Excerpt from Gorman and Sneyd 1986

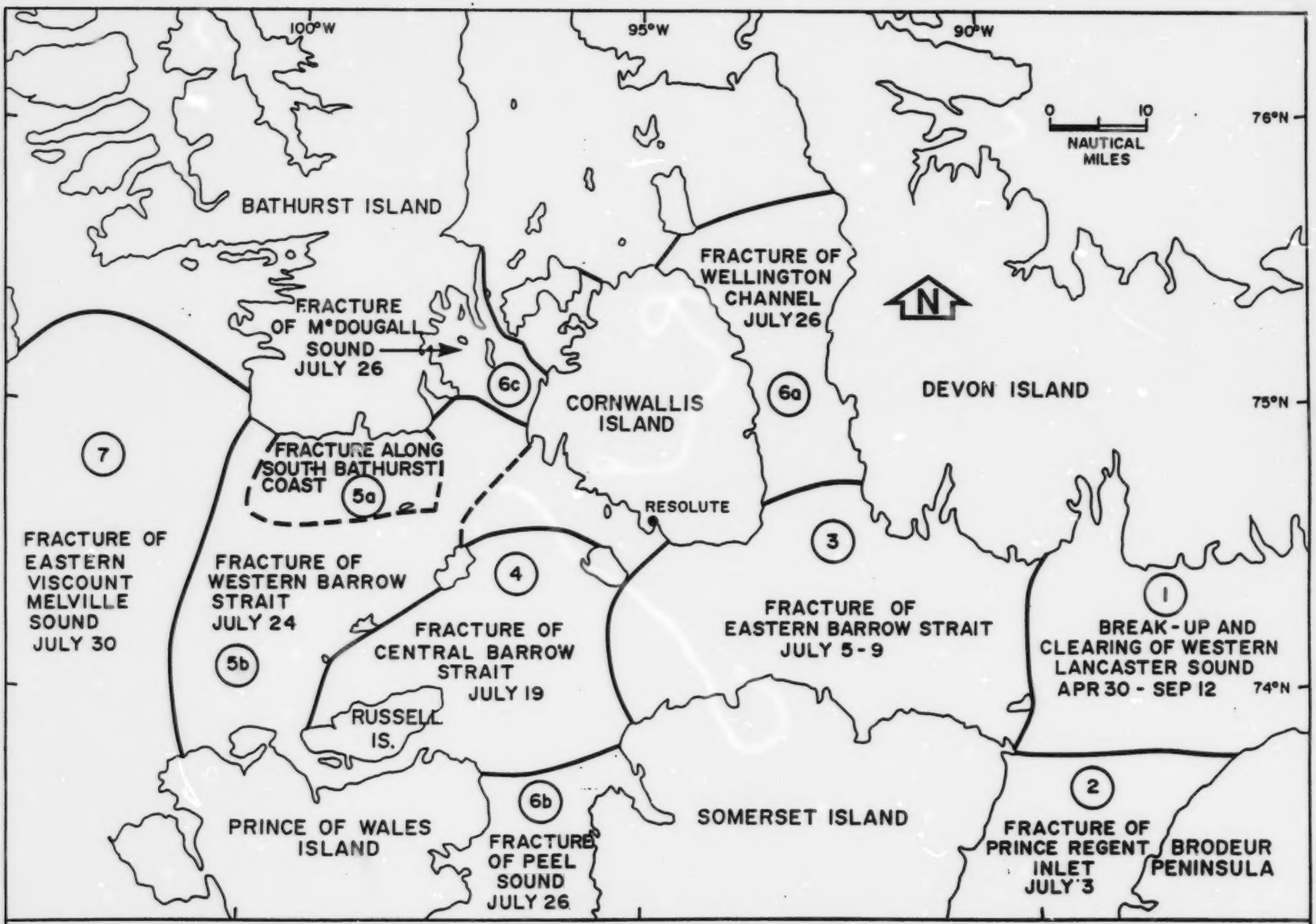

Figure 2.2 SEQUENCE AND AVERAGE DATES OF FRACTURE OF BARROW STRAIT

Table 2.9

Dates of Formation of mostly open water route to Austin Channel from central Barrow Strait across southern Bathust Island.

Year	Date
1974	August 25
1975	August 20
1976	August 25
1977	July 30
1978	September 1
1979	August 28
1980	August 31
1981	July 28
1982	August 3
1983	August 1
1984	July 28
1985	August 5

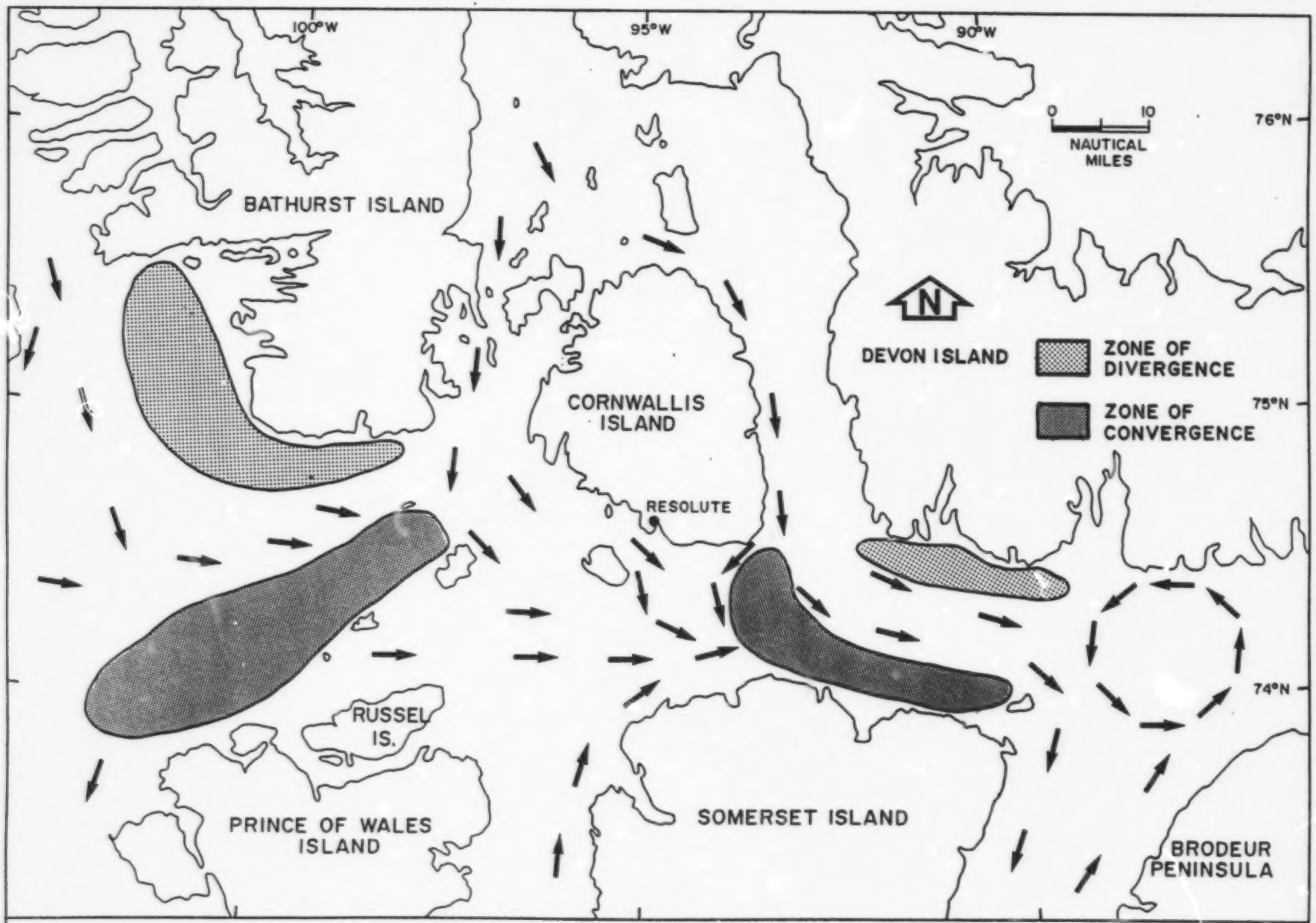

Figure 2.9 GENERALISED FLOW OF ICE IN BARROW STRAIT
ICE PRESSURES ASSOCIATED WITH ZONES OF CONVERGENCE

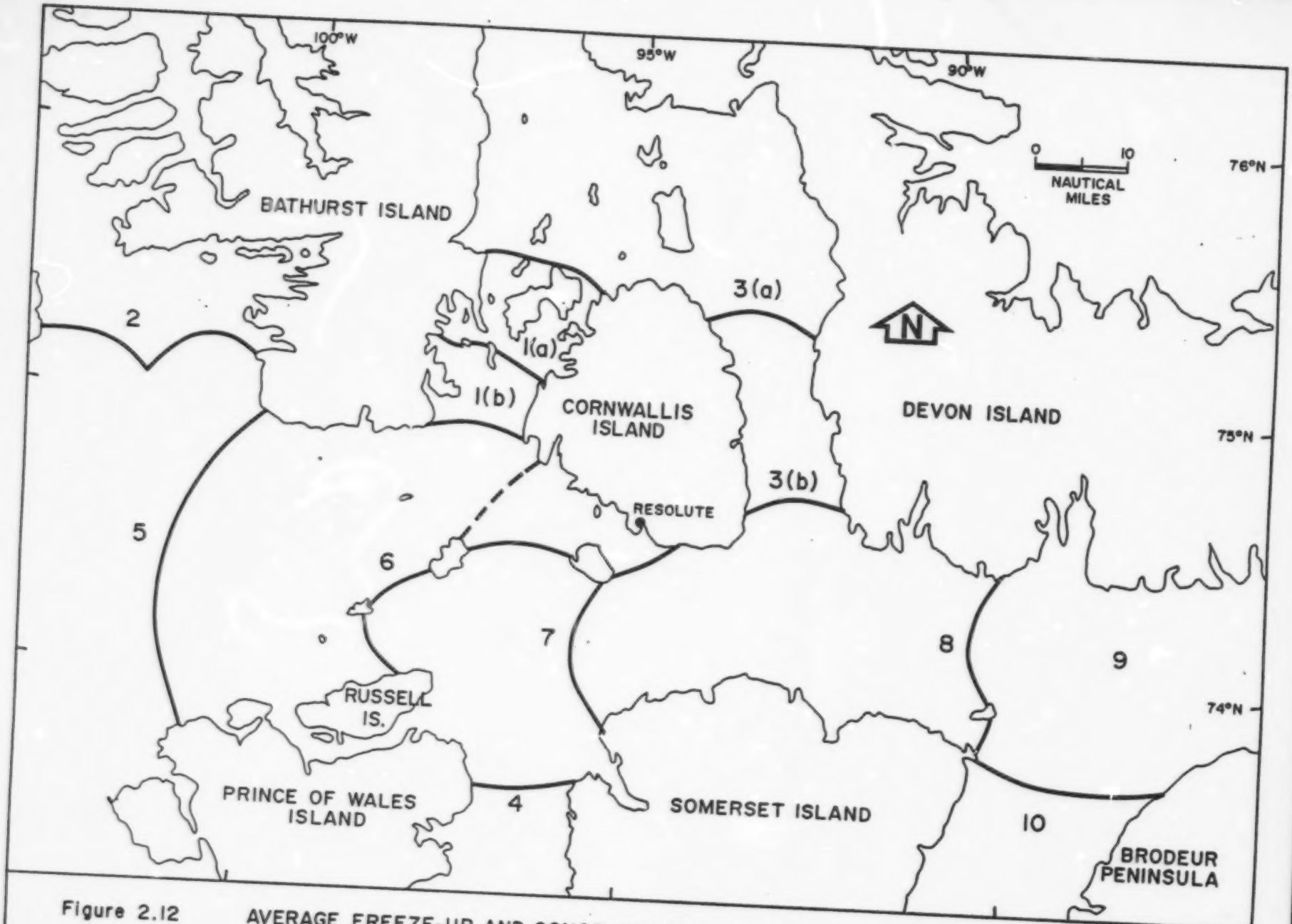

Figure 2.12 AVERAGE FREEZE-UP AND CONSOLIDATION PATTERNS - SEE TABLE 2.10

Table 2.10

Average Date and Range of Occurrence of Freeze-up and Consolidation in Barrow Strait 1974-1985

Event	Average Date of Occurrence	Range
1.(a) Consolidation of Northern McDougall Sound	October 17	September 28 - November 6
1.(b) Consolidation of Southern McDougall Sound	October 26	October 5 - November 24
2. Consolidation of Southern Austin Channel	November 8	October 8 - November 26
3.(a) Formation of Northern Wellington Channel Ice Bridge	November 15	October 18 - December 20
3.(b) Formation of Southern Wellington Channel Ice Bridge	December 8	November 4 - January 29
4. Consolidation of Northern Peel Sound	November 28	November 6 - January 9
5. Western Barrow Strait Ice Bridge Formation	December 3	November 19 - December 27
6. Formation of Russell Island Ice Bridge	December 14	October 10 - January 5
7. Formation of Griffith Island Ice Bridge	January 9	October 24 - February 28
8. Formation of Prince Leopold Island Ice Bridge	February 2	December 11 - April 11
9. Consolidation in Lancaster Sound	February 26	November 27 - March 23
10. Formation of Northern Prince Regent Ice Bridge	March 5	December 3 - April 10

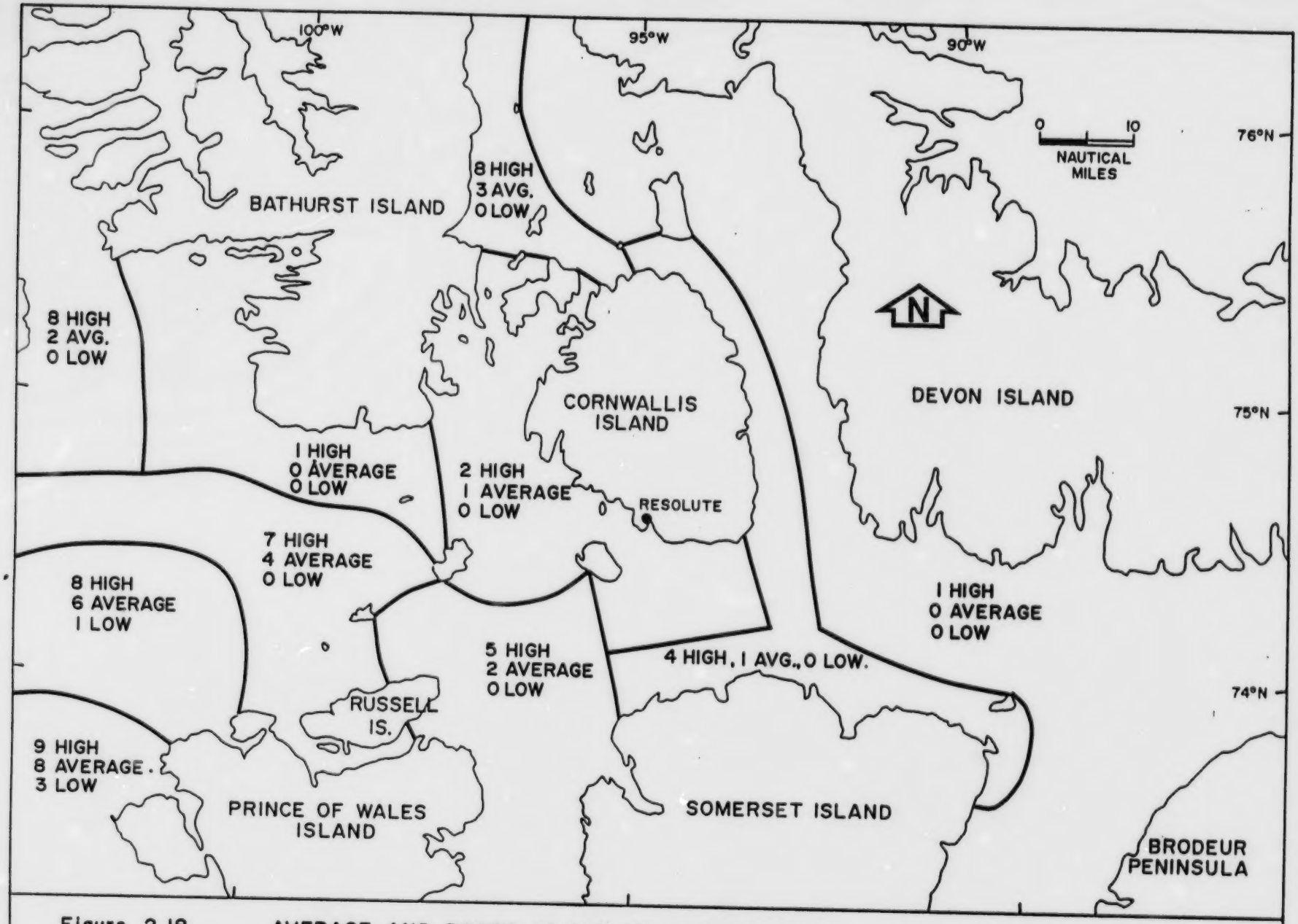

Figure 2.18 AVERAGE AND RANGE OF OLD ICE DISTRIBUTION

Appendix B

Example of Medium Range Analysis

Status Report #4
Meteorological and Ice Conditions in the Canadian Arctic

July 5, 1989

Prepared by:

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Status Report #4

1.0 Introduction:

This report is the fourth in a series of status reports being produced by Operations Development personnel for the M.V. Arctic's 1989 shipping season. This report updates ice and weather conditions developing in the eastern and central Canadian Arctic, and presents the results of a low level ice survey undertaken in the Bent Horn area by Canarctic in late June.

The analysis contained in this report addresses three situations:

1) A Summary and outlook for the M.V. Arctic's first voyage to Cominco's Polaris Mine.

2) A brief outlook for Type A and B ship access to Nanisivik and Polaris for August.

3) An initial summary and outlook for the M.V. Arctic's voyages to Panarctic's Bent Horn oil terminal in August.

Meteorological data from Resolute Bay, Mould Bay and Cambridge Bay along with recent satellite imagery were gathered from Ice Centre A.E.S. and used in this analysis. In addition, information gathered from an aerial survey undertaken on June 29, 1989 by Canarctic of the ice conditions leading to Bent Horn is used in this report. Information contained in this report is current up to and including July 4, 1989.

2.0 Meteorology

Daily average temperatures were well below normal during May, 1989, for Resolute Bay but have rebounded to near normal

values for the month of June. Daily average temperatures have been above freezing at Resolute since mid June with the monthly mean temperature being 0.6 C above normal for the month. Figure 1 illustrates the fluctuation of daily mean temperatures about the 30 year mean for Resolute Bay thus far for 1988/89.

The temperature pattern for Mould Bay, located west of Bent Horn on Prince Patrick Island, has been similar to Resolute Bay with daily mean temperatures 1.0 C above average for June. Figure 2 illustrates the fluctuation of daily mean temperatures about the 30 year mean for Mould Bay thus far for 1988/89. Cambridge Bay, located to the south of Resolute on the south shore of Victoria Island, has recorded daily average temperatures 3.3 C above normal for June, indicating that temperatures increase more above average as one moves south from Resolute Bay.

In addition to the average to lightly warmer than average temperatures, local residents report a greater than normal amount of rainfall for June. This rainfall, combined with the melt of the large amount of snow accummulated over the winter, is providing a large extent of water on the ice surface in the Canadian Arctic this spring and summer. An accummulation of a large amount of water on the ice surface has two important affects:

1) Surface water increases percolation into the ice causing a softening and weakening of the ice cover.

2) Surface water greatly reduces the reflective albedo of the ice surface greatly increasing the absorption of solar radiation which accelerates decay.

3.0 Ice Conditions:

The limit of winter consolidation remains as described in Status Report #1. The eastern limit, at Brodeur Peninsula in

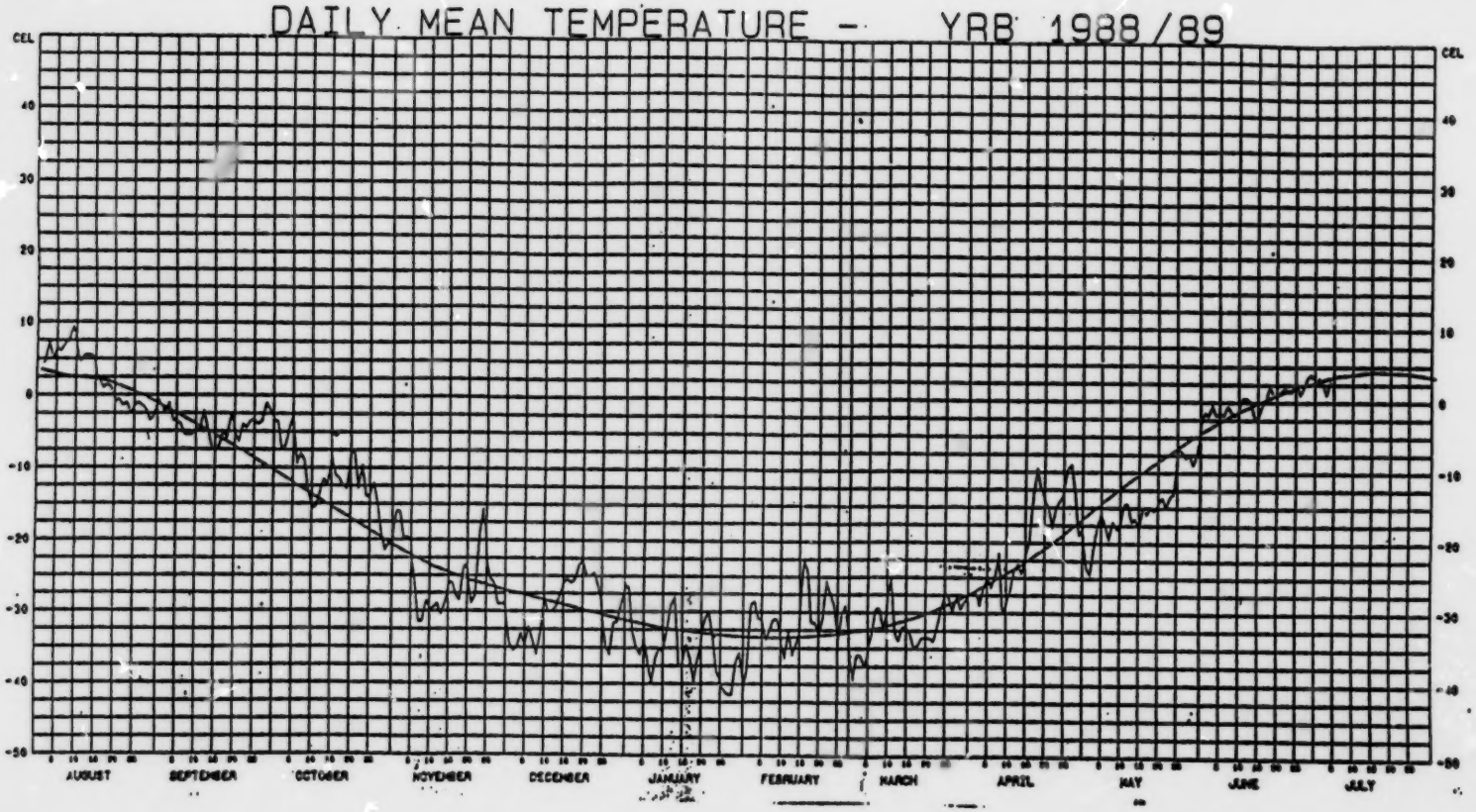


Figure 1: Daily mean temperatures about the 30 year mean value for Resolute Bay, N.W.T., 1988/89.

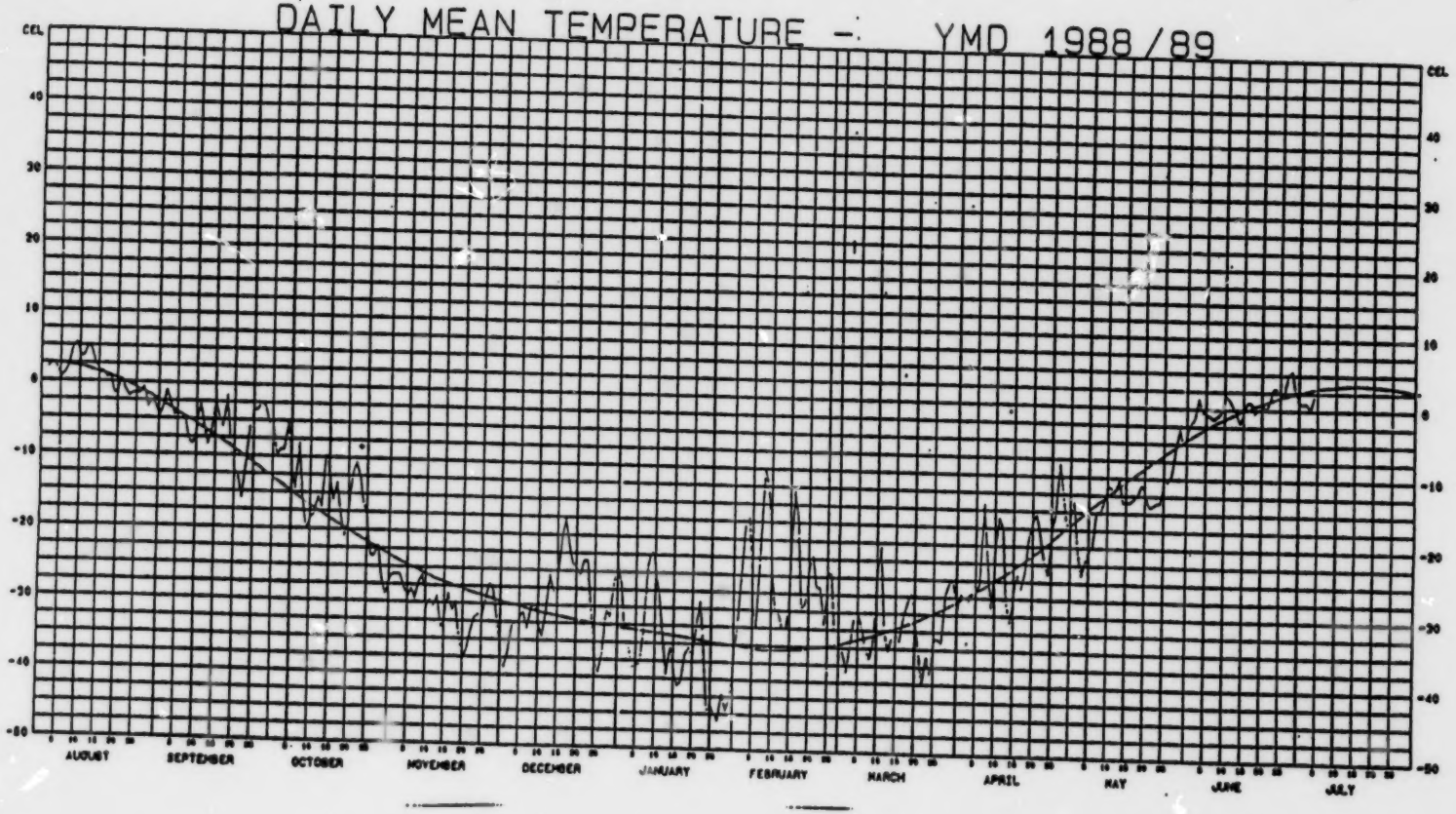


Figure 2: Daily mean temperatures about the 30 year mean value for Mould Bay, N.W.T., 1988/89.

western Lancaster Sound, as well as the ice edge in Admiralty Inlet, remains consolidated at the beginning of July. Eastern Lancaster Sound and northern Baffin Bay are predominantely open water with nine to nine-plus tenths first year ice remaining in Baffin Bay. These consolidations are on average with what can be expected at this time of year. However, the state of decay evident in the ice (ie. extensive amount of surface water and thaw holes) as found by Canarctic during the aerial survey was much greater than average, particularly in Admiralty Inlet, MacDougall Sound, Erskine Inlet and Arnott Strait. The ice in Barrow Strait and western Lancaster Sound, although not as decayed as the above mentioned waterways, were none-the-less in an advanced state of decay. The icebreaker CCGS Sir John Franklin penetrated 60 nautical miles into the ice edge in western Lancaster Sound reaching Radstock Bay, Devon Island, without encountering any difficulties by July 4.

4.0 Forecast

The apparent advanced state of decay of the ice cover indicates that 1989 will be an above average break-up year in the Canadian Arctic with fracturing occurring earlier and more extensive than normal. This represents the third year in a row that average or above average break-up conditions have been experienced in the Canadian Arctic. The fracture of western Lancaster Sound and eastern Barrow Strait west to Resolute Bay should occur any day now, likely before the end of the second week of July at the latest. The fracture of central Barrow Strait should follow in the third week of July and will include the fracture of Wellington Channel, MacDougall Sound and Admiralty Inlet. The complete fracture of the remainder of Barrow Strait and Viscount Melville Sound should be complete before the end of the fourth week of July. This fracture sequence will be on or slightly earlier than normal.

4.1 M.V. Arctic Access to Polaris in Mid-July

Owing to the extensive melt now occuring in the Canadian Arctic, the M.V. Arctic will not encounter any difficulties on her first voyage to Polaris this year, scheduled on or near July 22, 1989. The ice cover in western Lancaster Sound, Barrow Strait and MacDougall Sound should be fractured and decayed resulting in no impediment to the Arctic.

4.2 Type A and B access to Nanisivik and Polaris for Early August

With the ice of Admiralty Inlet so heavily decayed this year, Type B ships will encounter little to no difficulty accessing Nanisivik in early August. Although some patches of drift ice may be encountered, this can be easily avoided with the assistance of the CCG icebreakers and due caution of mariners.

With the consolidated ice edge in Lancaster Sound being 70 nautical miles further east than normal, a larger amount of remnant first year ice floes will be present in Lancaster Sound and Barrow Strait this August. Therefore, although Type A and B vessels should be able to access Polaris by the end of the first week of August, caution should be exercised to avoid the drift ice likely to be present in the shipping channels.

4.3 M.V. Arctic Access to Bent Horn

Synthetic Aperture Radar imagery of the ice conditions in Byam Martin Channel, Erskine Inlet and Arnott Strait was collected by Canarctic in March, 1989. Interpretation of this imagery revealed high concentrations of old ice frozen into the winter ice matrix in all access channels leading to the Bent Horn terminal site. Based on these potentially difficult conditions, Canarctic undertook a survey in late June of the ice conditions

leading to Bent Horn. The ice conditions in the access channels to Bent Horn showed signs of significant decay with extensive amounts of surface water and thaw holes evident in both the first year ice and old ice. Based on these conditions and the known historical record, the following sequence of break-up events can be expected for the Bent Horn region this summer.

The first event in the break-up sequence will be the fracture of southern Austin Channel. This will likely occur before the end of the fourth week of July this year co-incident with the fracture of eastern Viscount Melville Sound to the south. The fracture of Austin Channel will be followed by the fracture of southern Byam Martin Channel to the north in the first week of August. The fracture of southern Byam Martin Channel will terminate with an ice bridge between Ile Vanier and Melville Island. Given the advanced state of decay of the ice cover this year, it is likely that this bridge will fracture before the end of August this year, possibly as early as the second week of the month. Erskine Inlet will completely clear of ice this year, an event that only occurs in approximately 50% of years. The Inlet will likely clear of ice by mid-August.

With the fracture of the Bent Horn region likely to be complete by mid-August, a large volume of old ice will be free to flow southward from northern Byam Martin Channel and the Sverdrup Basin until freeze-up. However, given the high degree of decay of the ice cover noted this year in the Canadian Arctic, it is likely that this old ice will not pose a hazard to a Class 4 vessel such as the M.V. Arctic. Similar conditions of old ice flowing southward through the Bent Horn access channels has occurred in three of the four previous years the M.V. Arctic has made voyages to Bent Horn and has not as yet proven to be a formidable barrier to the vessel.

Therefore, for the first voyage to Bent Horn in mid-August, the sea ice should be heavily decayed and undergoing the

completion of fracture in the area. The high concentration of old ice around the terminal site may still be present but will likely be so decayed as to pose little difficulty to the vessel. For the second planned voyage in mid-September, the ice conditions will be quite different as the fracture of the ice cover to the north of Bent Horn will be well advanced. A significant volume of old ice will be present in the Bent Horn access channels flowing southward from Byam Martin Channel and the Sverdrup Basin. Although the ice will likely be weakened by the warm summer temperatures due caution should be exercised by the navigating officers to select the optimum route to the terminal site for the voyage.

5.0 Next Update

The CCGS Sir John Franklin will be attempting a crossing of the southern route of the northwest passage to the Beaufort Sea (Peel Sound, Victoria Strait, Coronation Gulf) in mid-July. The ease by which the vessel is able to break the consolidated ice in this area will give valuable clues to the true extent of the ice decay in the Canadian Arctic this summer. The next status report will be produced in mid to late July and will be focused on the ice conditions developing in the Bent Horn area.

Appendix C

Far Range Resolution Increase

One of the primary products of radar data acquisition will be the production of a radar map (refer to appendix G) that will be used for the purpose of correlating the radar to the SAR imagery. Conventional marine radar equipment is designed for target avoidance and not for imaging purposes. Standard designs, guided by a cost performance compromise, use antennas with a minimum beamwidth of .8°. At a range of 3 nautical miles (6 nautical miles required for ice navigation), the standard beamwidth will yield a maximum resolvable feature size of 75 meters. Such a low azimuth resolution, while perfectly adequate for target detection and avoidance, will not be sufficient for mapping purposes. SAR imagery has a resolution of 15 meters/pixel. The goal of resolution increase is to match the 15 meters/pixel without having to resort to non-standard radar equipment.

At a resolution of 15 meters, the maximum range for standard radar equipment will be .6 nautical miles. Beyond that range, the resolution will steadily fall off and the picture quality will degrade. Some means must be found to increase the image resolution beyond the .6 nautical mile range. Several options are available and must be considered:

1) Use higher frequency radar. The shorter wavelength will produce a narrower beamwidth for a given antenna length.
2) The use of a longer antenna will produce a narrower beamwidth and therefore increase the resolution.
3) Use signal processing techniques to extract information contained in the radar signals.

The third approach is the most likely to be used, since it does not involve the replacement of existing hardware and allows to use standard equipment. This document describes a technique that is contemplated for increasing the resolution of the radar image at far range.

The technique is based on the fact that along an arc of, the antenna aperture θ_B acts as a convolution window with a width of $r\theta_B$ (r = range). The convolution process essentially acts as an integration of the data framed by the "integrating" window. It is proposed to take advantage of the difference between signals generated by windows of different sizes along the same arc to recover some of the information lost through the integration process. For a given data wave form called the "original data" integration over two window lengths should produce results with different amplitudes. The wider the window, the higher the amplitude of the result from the integration over a given data segment (taking into consideration the difference in window size).

Two windows of different but similar size (say no more than 15% difference) are chosen and labelled window **A** and window **B** and **A** > **B**. If the leading edges of windows **A** and **B** are made to correspond on the original data, then the difference between the integration over **A** and **B**, noted $\underline{A} - \underline{B}$ corresponds to the integration in a window of size **A-B**, referenced at **B**. In this particular case, the resulting window size would be around 15% of either of the original windows. Referring to figure 1, a simulation has been done using random data. Waveform **"A"** is the result of the integration (summation in this case) in a moving window of relative length of 12 units, while waveform **"B"** is the result of the integration in a window of 8 units.

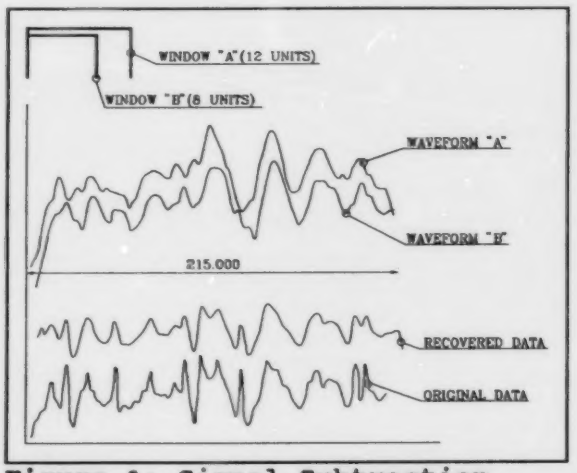


Figure 1: Signal Subtraction Process

The original data has a total relative length of 215 units and is shown at the bottom of the figure. The recovered data has been scaled properly and shifted from the original data waveform. According to the given dimensions, the waveform resulting from the subtraction of **A** and **B** should correspond to a window width of 12-8 = 4.

There are several ways to implement this process, and it is severely limited by the signal strengths and noise levels at far range. Nevertheless, using scan to scan integration and low noise amplifiers, it should be possible to improve on the resolution available from standard marine radars having an antenna beamwidth of 1° or so. Two methods have been considered for the implementation: using two radar antennas having different beamwidths, or using recorded data from the same antenna but at different ranges. The arc described by a radar antenna gets smaller as the range is decreased. As a selected target gets closer to the radar antenna, the antenna beamwidth defines a smaller window around the target. The variation in effective window size caused by a change in the range can be used for the subtraction process. The second method is the most promising and does not require the installation of a second antenna.

In addition, in the case of the two antennas, the signal generated by the wide beamwidth antenna (lower gain) will be weaker than the one generated by the narrow beamwidth one. Also, for the one antenna system, the close range signal (short arc) will be stronger (closer range) than the far range signal. In both cases, the signal strength is the strongest for the short arc case. Therefore some signal calibration is necessary in preparation of the subtraction process which requires that the long arc (wide integration window) case is associated with the highest amplitude signal.

For the implementation of the one antenna process, the following procedure has been worked out and is explained for one arc of samples located at a mean range **R** from the antenna. Figure 2 shows the difference in arc length created when the ship moves from point **P1** to point **P2**. The antenna beamwidth θ_B has been greatly exaggerated on the figure to show the effect. In reality, the antenna beamwidth is in the order of .8° to 1.5°. The arc difference can be worked out as follows:

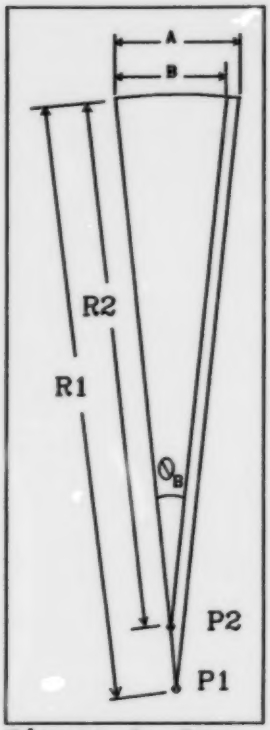


Figure 2: Arc Length Reduction

s = arc segment described by the antenna beamwidth at range **r**

θ_B= antenna beamwidth in radians

$s = r\theta_B$

$ds/dr = \theta_B$

$\Delta s = \Delta r\theta_B$

It turns out that the variation in arc segment length caused by a change in **r**, is independent of the absolute value of **r**. Therefore, within certain limits, for a desired resulting resolution, only the range difference need be specified. In figure 2, **A-B** will always be equal to **(R1-R2)** θ_B, regardless of the absolute value of **R1** or **R2**.

Since the vessel is moving in one direction, some problems will occur with targets outside the heading axis of the ship. The further away from the central axis, the more distortion will exist because of the change in bearing relative to the target. The arc variation effect used to implement the subtraction process, can only be used for targets located ahead of the ship's motion. As targets get closer to 90° from the ship's heading, a distance **D** along the main axis will result in an angular movement

only. Because of this effect, there is a maximum angle from the ship's heading at which this method can be applied. Fortunately, the area ahead of the ship is the area of interest. Figure 3 shows the geometry involved.

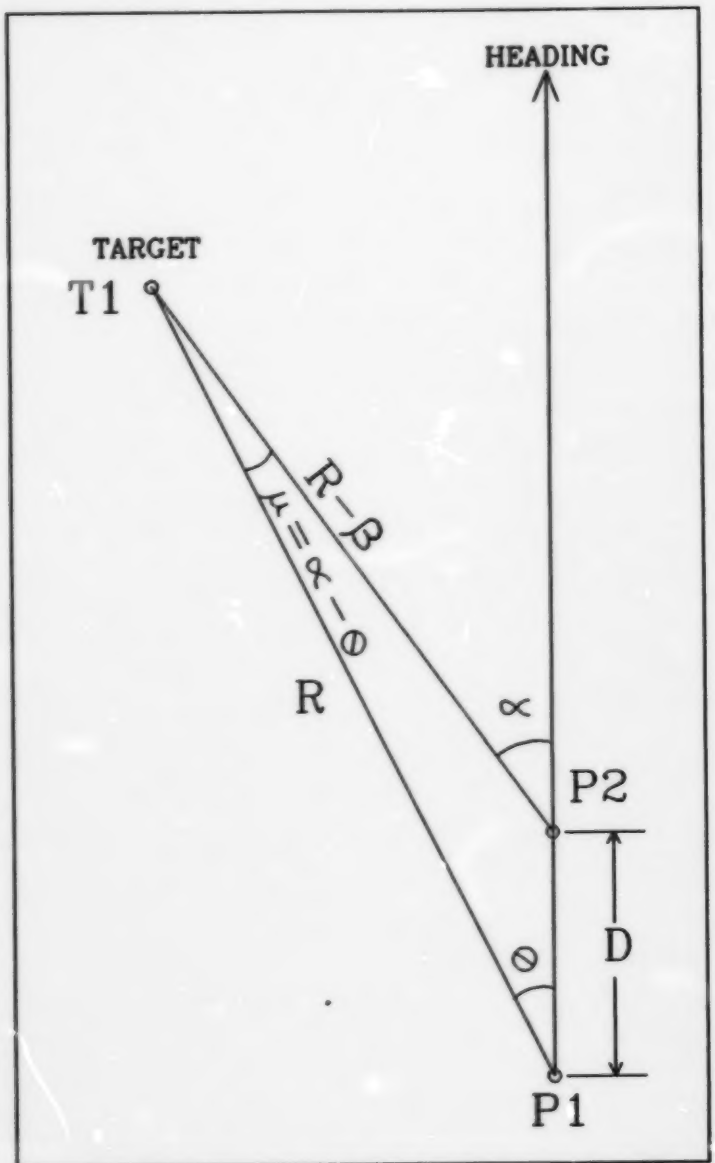


Figure 3: Resolution Increase, Target Geometry.

The main limitation here is the maximum allowable angle μ resulting from the change in position from **P1** to **P2** relative to target **T1**. Figure 4 will help in the following discussion on the maximum angle μ. The arc segment corresponding to θ_B has a resolution thickness σ that is related to the transmitted pulse width W_p in the following manner:

$\sigma = W_pC/2$ (derived from the speed of light and the round trip travel time of the radio wave)

The arc segment **s** around target **T1** is rotated by the angle μ. As the segment is rotated, its thickness will cover different areas depending on the viewing angle variation μ. The angle μ must be small enough so that the area **H** covered by the arc segment thickness will not vary by more than say 15%, thus the following calculations:

$H - \sigma s$

$\Delta\sigma$ - Linear rotation of arc segment s about target T

$$\Delta\sigma = \frac{s\mu}{2}$$

$$\Delta H = 4\frac{\Delta\sigma s}{2x2} - \Delta\sigma s$$

$$\frac{\Delta H}{H} = \frac{\Delta\sigma s}{\sigma s} = \frac{\Delta\sigma}{\sigma} < .15$$

$$\Delta\sigma < .15\sigma$$

$$\frac{s\mu}{2} < .15\sigma$$

$$\mu < .3\frac{\sigma}{s} \quad \left(\sigma = \frac{W_pC}{2} \text{ and } s = r\theta_B\right)$$

$$\mu < \frac{.15\,W_pC}{r\theta_B} \qquad (1)$$

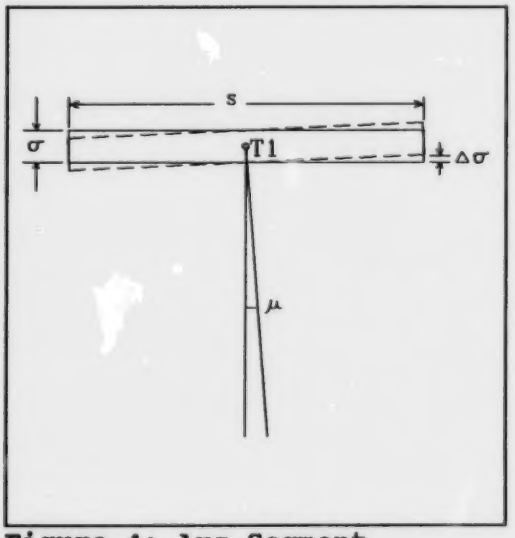


Figure 4: Arc Segment Calculations

Referring back to figure 3, the following calculations apply:

θ = Angle relative to ship's bow of target T1 viewed from P1

α = Angle relative to ship's bow of target T1 viewed from P2 (at a distance D from P1)

μ = Angle at T1 generated by the change in position from P1 to P2

r = Range from P1 to target T1

β = Difference ir range to target T1 generated by a change in position from P1 to P2

Therefore:

From the sine rule

$$\frac{r-\beta}{\sin\theta} = \frac{D}{\sin\mu}$$

$$\sin\mu = \frac{D\sin\theta}{(r-\beta)}$$

For small angles, $\sin\mu \approx \mu$

$$\mu \approx \frac{D\sin\theta}{(r-\beta)} \qquad (2)$$

From the cosine rule;

$$D^2 = (r-\beta)^2 + r^2 - 2r(r-\beta)\cos\mu$$

$$D^2 = (2r^2 - 2\beta r)(1-\cos\mu) + \beta^2$$

For small angles,

$$\cos x \approx 1 - \frac{x^2}{2}$$

Thus;

$$D^2 \approx (r^2 - \beta r)\mu^2 + \beta^2 \qquad (3)$$

Combining (3) *and* $(2)^2$,

$$\mu^2 = \frac{[(r^2 - \beta r)\mu^2 + \beta^2]\sin^2\theta}{(r-\beta)^2}$$

and rearranging,

$$\sin\theta = \frac{(r-\beta)\mu}{\sqrt{r(r-\beta)\mu^2 + \beta^2}} \qquad (4)$$

Combining (1) *and* (4),

$$\sin\theta = \frac{(r-\beta).15\, W_p\, C}{r\,\theta_B \sqrt{r(r-\beta)\dfrac{.09\, W_p^2 C^2}{r^2\theta_B^2} + \beta^2}}$$

Setting $e = \dfrac{r}{r-\beta}$

remembering that $\sigma = \dfrac{W_p\, C}{2}$

and that $\Delta s = \Delta r\, \theta_B = \beta\theta_B$

then;

$$\sin\theta = \frac{1}{\sqrt{e + \dfrac{e^2\, \Delta s^2}{.09\, \sigma^2}}} \qquad (5)$$

To solve equation 5, β is calculated from the desired Δs (pseudo beam width resolution) and the actual antenna beam width θ_B. The equation is then solved for the desired ranges. For a transmitted pulse width W_p of 75 nS, a desired Δs of 15 meters and ranges between 2 and 6 nautical miles, the resulting angle θ is approximately 11° and changes very little. The method would then be useable, for the above conditions, within a triangle of about 22° ahead of the ship. If the transmitted pulse width is reduced, or if the pseudo resolution is reduced (Δs is increased), this angle will narrow.

Signal calibration procedure:

Classical radar theory describes the standard radar equation as follows:

$$P_r = \frac{P_t G^2 \lambda^2 \sigma_t F^4}{(4\pi)^3 R^4 L} \qquad (6)$$

Where:

P_r = power received
P_t = power transmitted
G = antenna gain
λ = radar wavelength
F = pattern propagation factor
L = system losses
σ_t = radar target cross-section
R = range to target

Replacing F in equation 6 by the appropriate model:

$$P_r = \frac{4\pi P_t G^2 \sigma_t (h_a h_t)^4}{\lambda^2 L} \cdot \frac{1}{R^8} \qquad (7)$$

Where h_a and h_t are respectively the antenna height and the target height.

For a given set of conditions and a single radar system, the first part of the equation remains constant and can be written as follows:

$$P_r = K_o / R^8$$

where K_o is a lumped constant that accounts for all factors.

When receiving the radar signal, the amplitude will be proportional to the electrical field and therefore, calculations should be based on the received field intensity E_r.

Therefore:

$$P_r = K_0 E_r^2 = \frac{K_1}{R^2}$$

$$E_r^2 = \frac{K_1}{K_0} \cdot \frac{1}{R^2} = \frac{K_2}{R^2}$$

$$E_r = \frac{K}{R^4}$$

Where K_0, K_1, K_2 and K are transitional constants used for calculation.

During the following calibration calculations, ratios will be considered for signals received at P_1 and P_2, where P_1 will be considered the furthest point. For simplification, the variable E_r will be reduced to simply E, since only the received signal will be considered.
Thus;

$$\frac{E_1}{E_2} = \frac{K R_2^4}{K R_1^4} = \left(\frac{R_2}{R_1}\right)^4$$

$$\frac{E_1}{E_2} = \left(\frac{R_2}{R_1}\right)^4 \qquad (8)$$

The receiver imposes the following process on the received signal:

$V = \beta + \mu \ln(E)$

Where:

V = voltage generated by the E field after the receiver

β = amplifier offset (unknown)

μ = gain factor (unknown)

Rearranging and introducing the variable X ;

$$V-\beta = \ln E^{\mu}$$

$$X = e^{(V-\beta)} = E^{\mu} \qquad (9)$$

Raising both sides of 8 to the power μ;

$$\left(\frac{E_1}{E_2}\right)^{\mu} = \left(\frac{R_2}{R_1}\right)^{4\mu} = \frac{X_1}{X_2}$$

$$\frac{X_1}{X_2} = \left(\frac{R_2}{R_1}\right)^{4\mu}$$

$$\ln X_1 - \ln X_2 = 4\mu \ln\left(\frac{R_2}{R_1}\right) \qquad (10)$$

since $\ln X = V-\beta$

$$\ln X_1 - \ln X_2 = (V_1-\beta) - (V_2-\beta) = V_1-V_2$$

replacing into (10);

$$V_1-V_2 = 4\mu \ln\left(\frac{R_2}{R_1}\right)$$

rearranging;

$$\mu = \frac{V_1-V_2}{4 \ln\left(\frac{R_2}{R_1}\right)} \qquad (11)$$

On the average, μ should have the same value for all sample sets. Therefore, a more precise value should be obtained from the average of the individual μ values.

The full data set should be analyzed and a value calculated for μ. Once a value has been calculated for μ, individual values for the E field should be calculated.

The equation:

$$V = \beta + \mu \ln E$$

can be transformed as follows;

$$e^{V} = e^{\beta} e^{\mu \ln E}$$

$$e^{V} = e^{\beta} E^{\mu}$$

$$e^{\frac{V}{\mu}} = e^{\frac{\beta}{\mu}} E$$

setting $\alpha = e^{\frac{\beta}{\mu}}$

$$\alpha E = e^{\frac{V}{\mu}}$$

Values for αE can be calculated along an arc, as seen from P_1 and P_2. The resulting values can be averaged, producing αE_1 and αE_2. According to signal theory, if a signal y_a is the output of a moving average operation with a window size A, and similarly for y_b and B, then:

$$\frac{\overline{y_a}}{\overline{y_b}} = \frac{A}{B}$$

therefore, the ratio

$$\frac{k\,\overline{\alpha E_1}}{\overline{\alpha E_2}}$$

(Where k is the calibration factor that must be found)

should be equal to the antenna beamwidth ratio we are trying to simulate.

Introducing the variable;

$\omega = \theta_{B1}/\theta_{B2}$

as the beamwidth ratio, the following calculations are made;

$$\frac{k\,\overline{\alpha E_1}}{\overline{\alpha E_2}} - \omega$$

thus;

$$k - \omega\,\frac{\overline{\alpha E_2}}{\overline{\alpha E_1}}$$

but since $\dfrac{\overline{\alpha E_2}}{\overline{\alpha E_1}} - \dfrac{\overline{E_2}}{\overline{E_1}}$

we have found the desired result.

Once **k** has been found, individual **αE** values as seen from P_1 and P_2 are multiplied by **k** and the subtraction process can be implemented.

Such limitations as signal to noise ratios, required dynamic range and other parameters directly related to the radar signal have not been considered in this brief analysis. The fact that the ice environment is static allows to consider that low signal levels and poor signal to noise performances can be compensated for (at least in part) by scan to scan integration. For example, the ship travelling at 10 knots would cover a distance of .8 nautical miles in 5 minutes. During the same period, a target area could be mapped at least 150 times over with corresponding signal strengthening. The possibility for improved signal quality improves as the ship slows down. Situation that corresponds to a worsening of the ice conditions and therefore to the need for better imagery.

Azimuth Measurements and Alignment Procedures

The above processing methods will require the system to be able to resolve very precise azimuth angles of the order of .01 degrees, corresponding to an azimuth converter of 14 bits or more. Not only must the azimuth converter have a high resolution, but the antenna azimuth transmitter mechanism must be capable of precisely measuring the desired angle. The installation or the modification of a precise azimuth measuring mechanism in existing antennas will be part of the G2 implementation task. Solutions to solve this problem will have to be planned concurrently with the G2 system design.

Parameters such as radar mast vibrations (longitudinal, vertical, transversal as well as torsional) will have to be taken into consideration. Antenna to transmitter mechanical coupling will be critical in maintaining the required accuracy. Backlash will have to be minimized, or its effects compensated for. Synchro/resolver non-linearities will have to be compensated for, and methods found to field align and calibrate all azimuth sensing devices. Sensor alignment should be performed without the need to physically access any of the components.

In addition to the azimuth measurement problem, the ship's heading must be measured with comparable accuracy. The failure to adequately measure the absolute bearing associated with each video data radial, will void any effort to construct a precise radar map. At this point, it would appear that a dedicated gyrocompass fitted with a precise synchro transmitter would be the adequate solution to the problem.

Appendix D

Radar Scan Conversion

Radar signal digitization and scan conversion has been the subject of many developments in the last decade, and many groups have developed radar signal processing units for solving specific problems associated with various applications. These radar signal processing units are generically called "Scan Converters" because of the most apparent function of these devices, which is transforming the image from polar to cartesian coordinates. Traditionally, these scan converters have performed the following tasks:

1) Analog processing of the incoming radar signal (STC, gain, low pass, etc..)
2) Digitization of the radar signal (typically to frequencies of 20 Mhz)
3) Conversion of the digitized image from polar to cartesian coordinates.
4) Implementation of special effects such as fading, orientation alignment, and in some cases image analysis.

In contrast, the scan converter for the G2 system will has to perform the following tasks:

1) Perform analog processing of the video signal such as STC (Sensitivity Time Control) in a predictable manner precisely controlled by the system.

   The most significant analog processing will be provided by a gain and offset control. The ability to control both parameters is crucial to maintaining the full dynamic range of the digitizing section of the radar data acquisition module. Under normal conditions, radar signals from the ice surface will vary by as much

as 50 dB to 60 dB over the range of interest (1 to 6 nautical miles). If no analog processing of the signal is applied, the gain and offset of the digitizer front end will have to be set to accomodate the strongest signals without saturating. If the digitizer has a 10 bit size, the available digitized dynamic range is 20 x log(1,024) = 60 dB. Strong signals (at close range) will be digitized at the full dynamic range of the digitizer. Far range signals, 40 dB to 50 dB lower, will only use up 10 dB to 20 dB of the available 60 dB because of headroom needed for strong signals. Because the signal variations can be predicted, the gain and offset of the front end can be changed in real time to match the characteristics of the digitizer. In this manner, vital information contained in the signal at far range will not be lost because the dynamic range of the digitizer is not fully utilized. In fact, far range data are more important than close range data, and any design compromises should be made in favor of the far range data.

2) Accurately measure the absolute azimuth of incoming radar video data.

As explained in appendix C, the accurate measurement of azimuth angles is critical to the accuracy of the radar map and other products derived from the radar data. In addition to accurate synchro transmitters and synchro converters, remains the problem of accurate calibration. Two levels of calibration must be considered:

a) Calibration of azimuth transmitter linearity

b) Calibration of antenna boresight and gyro reference

Transmitter linearity pertains to the error curve inherent to the synchro construction and is unavoidable. The synchro non linearity is not a problem if the error curve is known. A problem arises when the synchro has to be changed in the field and no error curve is available for the replacement device. Even if the error curve was available for the new device, a number of events could occur (cable replacement, circuit non linearity etc.) that would invalidate a manufacturer supplied error curve. For this purpose, the system should be given the means to dynamically calibrate the azimuth information using on board references. Transmitter linearity curves can be generated by using information from digital shaft encoders (they typically have less resolution but are precisely incremental in nature) in combination with the angle supplied by the synchro transmitter. If the antenna is rotating at a constant speed, the antenna angle can be extrapolated from the angle measured at regular interval by the shaft encoder. The extrapolated angles can be compared to the angle measured by the synchro transmitter. Statistically, over a great number of measurements, the required precision can be reached and the synchro transmitter calibrated. This method is most interesting, since calibration could be performed on a regular basis and the full accuracy of the system maintained.

The calibration of the antenna boresight can be performed by using live targets in an uncluttered environment, or use the results of image analysis of the different radar sources to adjust the offset for a

best match. Modern image analysis techniques such as autocorrelation and others can help match the orientation of images produced by different antennas to a very high tolerance. Once images have been calibrated to each other, absolute azimuth angles can be figured out using known targets at far range aided by visual identifications of such features as bridges, icebergs and others. The above described process can be repeated on a regular basis to keep the system accuracy within specs. Alternately, a low power transmitter can be fitted at the ship's bow, facing the radar mast, and the signal used as an azimuth reference.

3) Digitize the incoming radar video at a maximum frequency of 40Mhz.

It is unlikely that SAR images will ever be collected with a resolution of better than 15 meters, mainly because this resolution is widely considered quite adequate. It would be unnecessary to attempt to produce a radar image with a higher definition than the above 15 meters/pixel. However, data processing might require higher resolutions in order to yield the best possible results even if the final product does not have more than 15 meters/pixel in resolution. Therefore, the system will be capable of digitizing the video information at the highest video bandwidth available (approximately 16Mhz) such that a digitizing rate of 40Mhz will be necessary. This digitizing rate can potentially resolve features of less than 3.5 meters in range.

4) Accumulate the required number of scans to perform the azimuth resolution processing and scan to scan averaging.

Such applications as scan to scan integration to increase signal to noise ratio at far range, will require a large number of scans for adequate results. In turn, the number of possible scans in a given time is dependent on the ship's speed and the range considered. Azimuth resolution processing (appendix C) will undoubtedly require a large amount of information to be collected in order to yield the precision needed. The production of images resulting from the combination of HH and HV signals will require twice the amount of data needed by a single source image. The number of radials and scans required to perform the above functions will be calculated from the needed processes, some of which are still under development. The method described in appendix C will require the system to retain in memory two sets of data corresponding to two bands of imagery approximately .5 nautical miles wide, 1 nautical mile apart and within an arc of 30° centred on the ship's bow. The same amount of data will be required for each data channel.

5) Perform the required azimuth resolution processing with the raw radar data, using such information as the absolute azimuth measurement, the ship's speed etc.

As mentioned earlier, the question of range resolution is critical to being able to build a radar map. In order to increase the range resolution, a large amount of processing will have to be performed on the incoming data before scan conversion. At this stage, all necessary polar coordinate processing will be

performed. The processing includes HH/HV processing (appendix F), azimuth resolution increase processing and others as required.

6) Perform the scan conversion using the azimuth processed radar data and such information as the ship's speed.

Once the polar formatted data has been processed, scan conversion will be performed to produce a cartesian coordinate image. The scan conversion process and the nature of the original data imply that some image pixels will be addressed more than once, specially near the centre. If more than one data item is available for a pixel, various methods are available to process the incoming data. Each additional data item can be averaged with all the previous ones available for that pixel. Alternately, the highest value can be used as the pixel value, or the last data item can be used. Other methods of scan conversion can be used, and the benefit of each would have to be evaluated. For the moment, pixel averaging is strongly preferred and will be implemented with other methods to be developed and tested in the future.

7) Perform a similar conversion for all sources of radar data.

Several sources of radar data will be available to the G2 system. On the X-Band radar, as many as three different channels could be available HH and HV narrow beamwidth and wide beamwidth HH antenna. These radar sources will be combined and processed in various ways to yield the desired image products corresponding to the various operating modes. Wether these data

conversions will be needed simultaneously or in sequence, will be largely determined by experimentation. However, the system should be able to process at least two full bandwidth radar channels simultaneously. The necessity for this amount of processing will be evaluated in the initial system trials.

8) Transmit the resulting data to the image processing module.

The totality of the data processed in the radar image acquisition module will be transmitted to the rest of the system for further processing. The intent of the radar image acquisition module, is to produce the highest definition, best quality cartesian radar image possible that can be further processed for ice navigation. The rate at which the images are to be produced should be decided by the operating mode and the ice environment. If a low image refresh rate is required, the extra processing time should be used to increase the quality of the produced images, by applying successive integration of the incoming data.

Appendix E

Radar Operational Parameter Control

Precise azimuth measurements, high bandwidth video, high digitizing rates etc., would be of limited use if precise control of the radar operational parameters cannot be exercised. When first conceived, the ice navigation system was considered an appendage to the existing marine radar system. In this configuration, the ice navigation system was to have no impact on the shipboard radar and was to be totally dependant on it. It is becoming clear that the G2 system, depending on the mode of operation, will need direct and precise control over the marine radar. Such parameters as signal gain, STC control, bandwidth, pulse width, PRF, antenna rotation rate and others, must be precisely controlled in order to get the accuracy and reliability expected of the system. At far range (say 6 nautical miles), the number of required radials to adequately cover an area will be very high, probably in the range of 40 or 50 radials/degree. This is especially true if azimuth processing must be performed.

There are two ways of getting this kind of radial density, either slow down the antenna until the rotation speed combined with the PRF produces the required resolution. Alternately, the speed of the antenna can be increased and the transmitter fired at precisely controlled antenna angles. In the second method, the area of interest must be scanned during successive rotations of the antenna, radials for each turn being fired at a slightly offset angle from the previous turn.

The first option does not require control of the firing instant but excessive time is lost waiting for the antenna to circle round back to the area of interest. In both cases, the same time would be required to complete the digitization of the area of interest. In the second approach however, the latency period would be much reduced allowing to monitor target movements outside the area of interest. In addition, at low speeds the antenna rotation rate is less stable and therefore cannot be relied upon to evenly distribute radials along the scan at

constant PRF. Because of antenna inertia, it can be expected that the antenna speed will be more constant at higher rotation rates. Higher speeds also make the antenna motor run closer to its design speed and therefore to its optimum running conditions.

The second method is more attractive because of the reduced latency period at higher antenna speeds. Much higher accuracy can be reached by firing the transmitter at known antenna angles, that have been calculated to "fill" in missing areas, taking into account ship's movements and antenna speed variations. Depending on the application, the ice conditions and the ship's speed, various settings for the antenna speed and transmitter PRF may be optimal. The best combination will ultimately be determined through experimentation.

In addition to the antenna speed and the transmitter firing moment, the system has to be able to select bandwidth, pulse length, tuning and gain settings. Depending on the application or the operating mode, short or long pulse lengths may be selected, with associated bandwidth. Even though the system will most frequently be operated at short pulse length, some situations will require the operation at a longer pulse length.

The radar system providing signals to the G2 system will also be used concurrently for traditional navigation and target avoidance. The IF section of most marine radar the receivers is normally designed to incorporate gain, STC and bandwidth controls. Any changes to the radar settings by the navigating officer, will have a direct impact on the characteristics of the signal provided to the G2 system. For maximum independency and fully controlled signal characteristics, a separate IF section should be installed in the radar receiver. The addition of this separate section would allow independent operation of the two systems, in as much as the G-2 system is given control of the radar PRF and transmitted pulse length.

Appendix F

HH/HV Radar Signal Processing

Navigation in ice covered waters will be well supported by the G2 system and many techniques have been developed, that will assist the navigator in the task of avoiding difficult or hazardous ice conditions. The same statement cannot be made for ice infested and partially ice covered waters. Navigation in these conditions is mostly a matter of avoiding hazardous ice in the form of multiyear ice floes or small size icebergs or otherwise difficult to detect hazards.

The shipboard radar will play a significant role in providing the navigator with reliable information about ice conditions ahead of the ship. The most confusing environment consists of partially ice covered waters with imbedded hard ice objects, such that the hazards become undistinguishable from their environment. In these conditions, the dual polarized radar will be used to discriminate between first year and multiyear ice objects. Efficient use of the cross polarized signals cannot be made without some form of signal processing involving both, the horizontally and vertically polarized channels. As of yet, no definite method has been worked out to combine the related HH and HV channels of the dual polarized radar. This type of radar has only recently been recognised as having a potential for hazardous ice detection and therefore research is still in its early stages. In addition, radar returns from icebergs and other dangerous ice objects vary widely with wetness conditions and surface temperature. Therefore, adequate processing of the HH and HV channels will depend on environmental conditions and the type of ice feature to be detected.

Appendix G

Radar Image Mapping

The radar/SAR correlation process is necessary to determine the ship's position on the SAR imagery. The only means of determining the ship's position on the SAR imagery is by comparing it to the shipboard radar imagery. This comparison process is referred to as the correlation process.

Originally, the correlation of the radar imagery to the SAR imagery was made visually, by having both images displayed on adjoining monitors, or otherwise positioning the SAR image (in hard copy format) close to a displayed radar image. Although the process was demonstrated as suitable and necessary, its implementation was difficult and in most cases limited by the quality of the radar image. Poor image quality, low resolution at far range (above 1.5 nautical miles) and limited range capability (3 nautical miles), limited the useful range of radar images to 2 nautical miles for the purpose of SAR correlation. Because of the reduced radar image range, recognisable features on both the radar image and the SAR image were not always available for correlation. In addition, the correlation of both images, if features were found, was often difficult if not impossible.

Recently, the concept of building a map of the radar image has emerged, that will eliminate most of the limitations of the current techniques for radar/SAR correlation. The construction of a radar map will extend the area (up to 100 nautical miles or more) over which the radar image can be compared to the SAR image to ranges far exceeding the boundary of real time radar images (3 to 6 nautical miles). The mapping process will involve sophisticated data processing that will increase the image definition (necessary for alignment purposes in the mapping process) to levels not attainable in the past. Higher definition will make identifiable features easier to see and thus facilitate the correlation process.

The range of the new arctic marine radar image is expected to be approximately 6 nautical miles. At that range, the processed image is expected to have a resolution close to 15 meters/pixel (using data processing techniques), equivalent to the maximum resolution of the SAR imagery. Using the resolution enhanced data, a section of imagery will be constructed to be appended to the radar map. Sections will have to be attached to the main radar map by using self referencing techniques. Corresponding features will be selected on both the radar map and the appended image section and used to align the new section to the main radar map. As many corresponding features as necessary will be selected for the attachment process. The attachment process will be critical, as small misalignments may result in considerable distortion that would render the map useless for correlation purposes.

Several information sources will be used concurrently to ascertain the validity of the appended image section position. Ship's speed calculated using the radar imagery and long range targets may be used to complement the attachment process. The precise measurement of the ship's heading, satellite positioning, precise radar range measurement, scan to scan integration, multiple radar signal combination, are among the data sources that are expected to be useful in the attachment process.

The radar image acquisition process will be such that new image sections will always overlap a portion of the map to which it must be attached. Therefore, the data contained in overlapping sections will have to be combined to the main map to yield the completed map. The attachment of new sections of map imagery will be performed by an averaging process, once the exact position of the attached section is known.

Depending on the quantity, the quality and the range of attached sections, the central area of the radar map is expected

to be of higher quality than at the periphery. It is also expected that as the ship moves away from encountered regions, data from the reverse direction can be used to enhance the existing map. Care should be taken not to introduce into the forward collected map, false data produced by the ship's passage. One important point to emphasize is that by definition of the mapping process, the ship's position relative to the radar map will always be known precisely. Once the radar map will have been correlated to the SAR imagery, the ship's position will be known relative to the SAR.

Appendix H

Radar/SAR Image Enhancement

It is often very difficult to match the radar imagery to the SAR imagery. Originally limited to the radar range, the radar image area that can be correlated to the SAR imagery has been extended many fold through the mapping process (see appendix G).

Several techniques have been proposed to assist the navigator in correlating the radar map to the SAR imagery, beyond the simple visually assisted process. One of the simplest process is to overlay the radar imagery on the SAR imagery and manually move the overlay to obtain the best positional match. Briefly experimented with, this method was found inefficient because of the confusing nature of the overlaid images and because there is not a direct correspondence between the radar and the SAR images.

A far more promising approach was developed by Cimmetry Systems of Montreal, during a project aiming at enhancing the radar imagery for the purpose of facilitating radar/SAR image correlation (Algorithms-Enhanced Radar Images, sponsored by the TDC). The method is based on the principle that it is much easier to correlate extracted features from the radar image than the total image. The number and the nature of extracted features can be fully controlled, and only selected types of features retained for correlation. The overlays containing extracted features are much simpler and much easier to correlate to the SAR imagery.

Several techniques were developed to extract visually identifiable features in the radar image. The original goal was the recovery of ice floe outlines and other prominent objects in the image. It soon became apparent that techniques suitable for ice floe extraction were not suitable for the extraction of other shapes in the image and vice versa. The result was a collection of enhancement techniques each suited to a particular class of image, and the extraction of selected types of features (lines,

floes, icebergs, etc.). The various enhancement techniques can be cascaded and combined to produce better results than single enhancement. From the processed images, extracted features are used to build a very simple overlay that contains only the outline of significant features from the original image. The produced overlay can then be translated and rotated over the SAR imagery until features in the overlay can be matched to corresponding features in the SAR imagery. The matching process was found to be surprisingly accurate and simple compared with the other proposed methods.

Recent experimentation (Milestone #5, SINSS Manning and Training Program, CCG executive services project No.T8080-9-4645/01-SZ) has shown that, at least for a certain class of image, extracted features from the radar image almost always correspond to some feature on the SAR image. What appears as a lead on the radar image, may in fact correspond to the interface between two ice floes in the SAR imagery. Even though it is not always easy to evaluate the exact nature of features on the radar image, these features will correspond to a feature on the SAR imagery; that is the crucial element. It turns out that it does not matter whether a radar image feature was properly identified or not, it will almost always correspond to some feature of the SAR image.

The fact that exactly corresponding features in the radar and SAR imagery are not necessary for correlation, relaxed the constraints on the kind of image enhancement that would give the best results. Consequently, enhancement techniques were devised to extract linear, curved, point targets and grouped features. Depending on the type of radar image, any of the above techniques, as well as combinations of them will be selectable by the system user and an overlay produced for correlation with the SAR imagery.

During experimentation, it was found that some of the features identified on the radar image were only dimly visible on the unprocessed SAR imagery, but were identifiable nonetheless. It has been argued that enhancing the SAR imagery to reveal weak details would bring out features that are not significant in terms of hazardous or difficult ice conditions. From this, it was decided that two kinds of SAR image enhancement would be necessary. Enhancement for the purpose of ice type evaluation and voyage planning, and enhancement for the purpose of correlation. The two enhancements are mutually exclusive and the resulting images are not compatible. Correlation enhancement for the SAR imagery will be necessary to exploit the full benefit of radar mapping.

Appendix I

Implementation Example

An example of a system implementation has been drafted and is presented here. This example is by no means the only way of implementing the system, but does provide a basis for discussion and in some cases helps clarify certain concepts. Diagram G-1 supplied with this appendix shows a block diagram of the proposed system.

Diagram G-1 shows a main system bus and secondary buses. The main bus is a 32 bit architecture (data and address), while the secondary buses are undefined at this point. The main bus will operate at 40 Mhz (a limitation of physical size and not of electronics), while the secondary buses may be faster because shorter. All buses are open in architecture and are expandable to the limit of the physical size specified by the adopted standard for the bus. To each bus and sub-buses, are connected modules for data processing, general processing, data entry and output, graphics display, and human interface. The total system will be implemented in the eurocard format.

In this section, the purpose and functionality of each module presented in diagram G-1 will be discussed. Two primary kinds of modules are proposed, intelligent and passive ones. Intelligent modules will have some degree of independence and will have the capability to perform specific tasks when instructed to. Intelligent modules will inherently incorporate a microprocessor plus a certain amount of dedicated memory. Passive modules are essentially address to devices only. Good examples of passive modules would be a memory card, or an analog to digital converter card.

a) Human Interface Module (HIM):
The HIM is the primary interface to the system and is much more than a physical link. The function of the HIM is to perform the interface between the entry devices and the system, and also interpret the various commands given

through the entry devices. It is in the HIM that the user interface will be implemented, translating user formatted commands and instructions to system commands. Such parameters as track ball sensitivity, digitizing tablet resolution or touch screen calibration will be handled by that module. The HIM will inherently be an intelligent module.

b) Graphics Output Engines (GOE):
The GOE will handle all graphics output functions. Some GOEs will have colour capability, while others will be limited to grey scale monochrome with very high memory capacity for fast pans and zooms. The exact configuration and command structure of the graphics subsection of the system will largely depend on the chosen architecture, but the underlying principles will remain. The GOEs should be semi intelligent modules that operate in close relationship with the High Capacity Image Memory Unit (IMU) and the Image Processing Unit (IPU) over the High Speed Graphics Bus.

c) Image Processing Unit (IPU):
The IPU will be a highly parallel processing machine used to perform very high speed image processing. Such processing as Relaxation Labelling, filtering, feature extraction will be executed by this module. The capacity of the IPU will be dictated by the application and the algorithms to be implemented, currently under development.

d) High Capacity Image Memory Unit (IMU):
The IMU will be exclusively dedicated to serving the graphics subsection comprising the IPU, the GOEs and the high speed mass storage unit. This will be a high capacity, high speed dual ported memory unit.

e) Mass Storage Control Unit (MSCU):

The MSCU modules will be standard interface devices for mass storage units. Most mass storage devices cannot interface directly with the host hardware and require a dedicated interface on a local bus such as the SCSI (Small Computer Standard Interface, pronounced "scuzi") or others. These modules are standard in any chosen hardware base and are commonly available. MSCUs are inherently intelligent devices since they must respond to various commands from the system, and potentially handle and monitor several mass storage units. At least two MSCUs will be installed on the system, one general purpose unit and one high speed high capacity unit for image processing purposes.

f) Hard Copy Interface Unit:
This unit will provide the necessary digital or analog signals required to interface to external printing devices. In addition to providing the proper signals to drive the external devices, the interface unit will provide device monitoring and protocol conversion as well as data buffering. This module may in fact consist of a micro computer resident on an 8 bit bus architecture (such as STD or G-64/96), along with the necessary serial/parallel analog/digital interface boards. This module will be intelligent.

g) General Processing Unit (GPU):
The GPU will perform all the necessary tasks that none of the individual modules have time to perform, or that cannot be conveniently implemented on other modules. Such tasks as database management/searches will be delegated to the GPU. Calculations such as satellite position and azimuth, vessel position and course, and any other computational tasks not <u>directly</u> related to any of the modules will be handled by this module. In case of failure of the GMU, the GPU could conveniently take over system management. The GPU

would most likely be a single board computer with inboard dedicated memory.

h) General Management Unit (GMU):
The GMU will be very similar in capacity and configuration to the GPU. The primary task of the GMU will be to handle real time events, delegating complex tasks to the GPU. Because the GMU work load will be kept to a minimum, important events will be handled in a timely fashion. The GMU will implement what can be called the system's "consciousness" that interacts with the user and essentially renders low level operations transparent to the operator.

i) System Working Memory:
The system's memory is a module that will be shared by all other modules. This unit will allow the implementation of such features as disk cache and data buffering. Data files that must be processed could be loaded in the system's memory until all processing is completed thus speeding the process and reducing the hard disk drive ware. Software routines too large to coexist one single module, could be temporarily stored in the system's memory until required by a module. The system's memory will be used during software development and during normal operation for various operations. The memory capacity is difficult to evaluate at this point, but first indications show that at least 30 megabytes of memory would be necessary.

j) Downlink Interface Unit (DIU):
The DIU will perform all the necessary interface and buffering tasks required to receive both facsimile format images, and S-Band digital images from satellites or other source. The unit will be equipped with an adequate buffer memory and possibly limited mass storage capability. The function of the DIU will be to activate and set up

individual receivers, receive and adequately format images, monitor and manage the receiving subsystem, and transfer received images to the system in a timely manner. The DIU will be a fairly complex module, possibly consisting of several components, and will inherently be intelligent.

k) Satellite Dish Control Unit (SDCU):
This module will be tasked with the alignment of the satellite dish antenna, or any other directional or semi-directional antenna for the DIU. The SDCU might be sophisticated to the point where it may actually perform servo calculations for the antenna mount. Depending on the level of complexity of this unit, it may be incorporated in the DIU along with the other functions and components.

l) Radar Image Acquisition Module (RIAM):
This module will digitize incoming radar video, process the resulting data to produce the required image (resolution enhancement processing, scaling, scan converting, integration etc.), temporarily hold the data if necessary and transfer the produced images to the graphics subsystem for further processing.

m) Radar Control Interface Module (RCI):
This module will control the radar system parameter such as pulse width, pulse repetition frequency, video bandwidth, antenna rotation speed, radar signal source, and even radar pulse trigger. These parameters can and should be varied to enhance the radar performance for specific tasks. This module should be intelligent but does not require a large processing capability. A significant amount of analog and digital data input/output will be required from that module. It is conceivable that the radar control interface module will be implemented in the same subsystem used for the Data Interface Module.

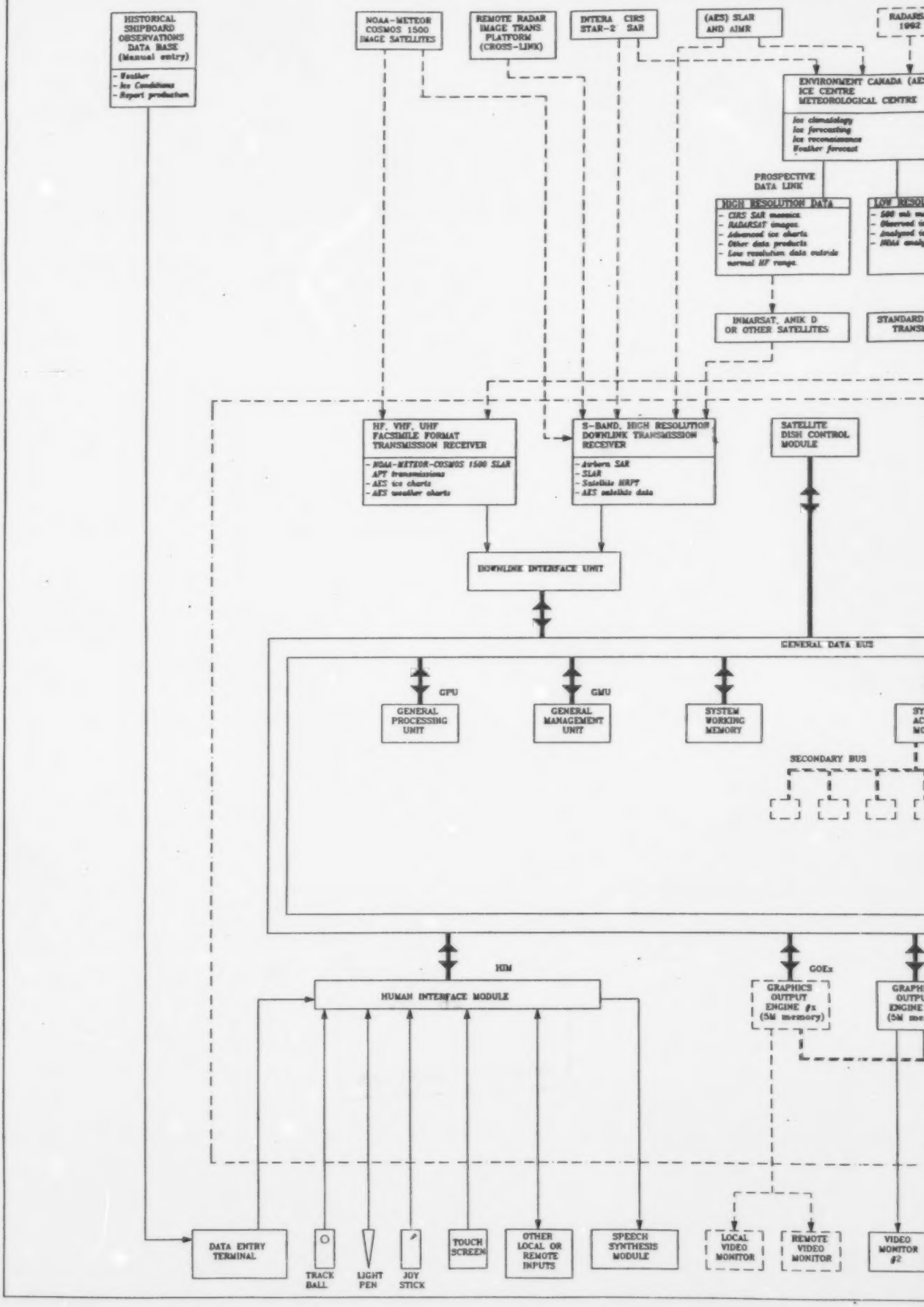
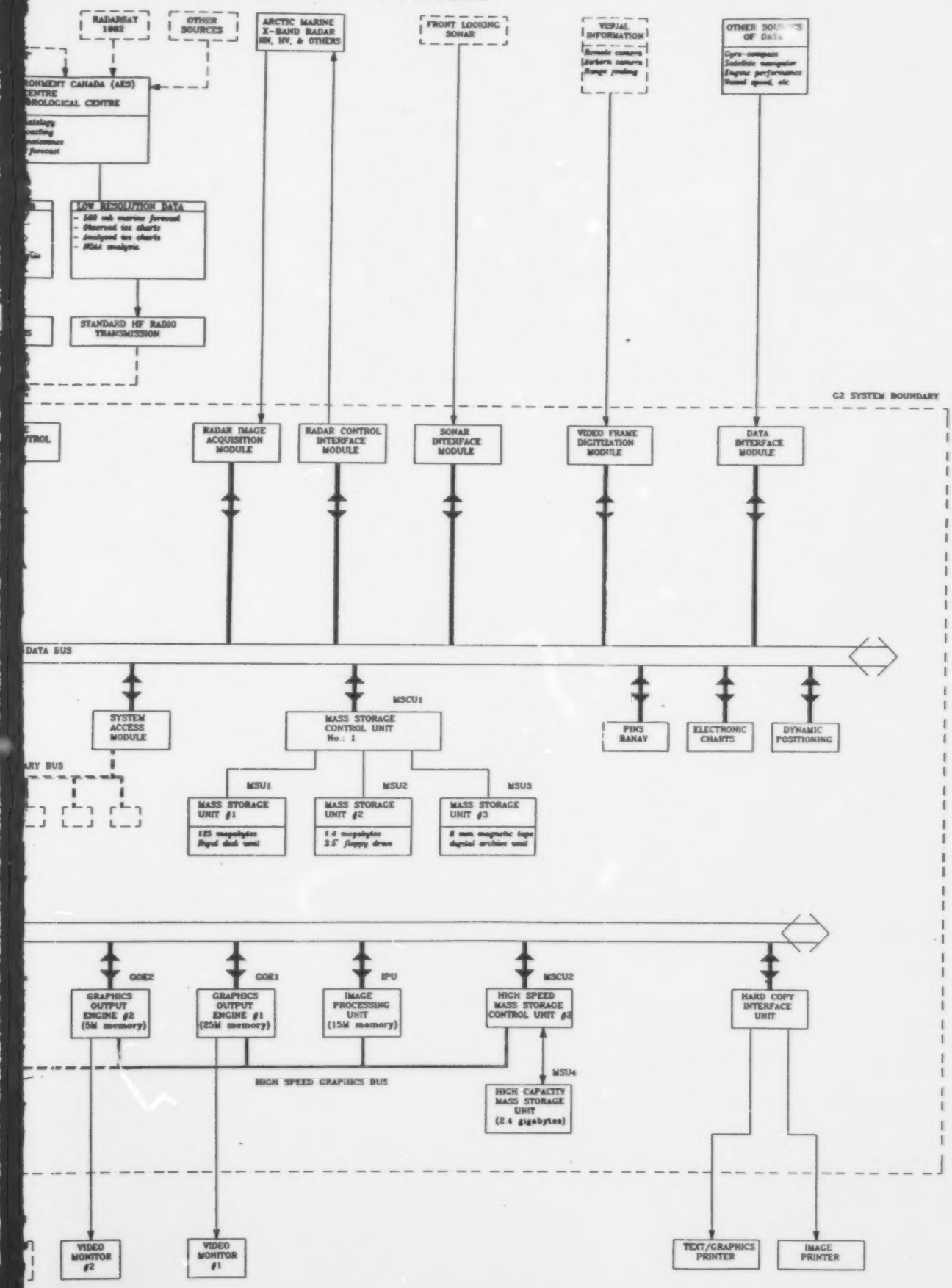
n) Sonar Interface Module:
This module has been included to provide an entry point into the G2 system for the front looking sonar presently under development. The data format, rate and quantity are not known at this point.

o) Video Frame Digitizing Module:
This module has been included to allow the entry of visual information from remote cameras or other visual information sources. The visual information to be digitized will represent still images of 1024 x 1024 pixels taken from remote sites. This will be a passive module.

p) Data Interface Module (DIM):
The DIM will interface to any digital or analog data sources that the G2 system requires to operate. Examples of the data sources include the ship's gyro compass, satellite navigator data, vessel performance data, vessel's speed and others. The data rate for each data source will be relatively low in comparison with the system's data handling capacity. Digital data rates will not exceed 1200 bauds, while analog data bandwidth will not exceed 1000 Hz. The DIM will most likely consist of a subsystem interfaced to the main bus and will incorporate significant processing capability.

q) Others:
Other modules represent specific applications entry points and will be considered intelligent modules having low to moderate data transfer requirements (2 to 10 megabytes/second) in burst mode. The exact nature and quantity of the data to be transmitted by each module will be determined by the application at the time of interface. Additional applications may include dynamic positioning, precise navigation, electronic charts etc..

SECOND GENERATION IC



TION ICE NAVIGATION SYSTEM